BUCKNELL UNIVERSITY LIBRARY
MAR 9 1953
LEWISBURG, PA.

ROYAL AERONAUTICAL SOCIETY 1866

Journal

of

THE ROYAL AERONAUTICAL SOCIETY

FEBRUARY 1953

CONTENTS

SECRETARY'S NEWS LETTER

NOTICES

REX PIERSON—AN APPRECIATION AND THE LESSONS OF HIS WORK — SIR A. H. ROY FEDDEN

MEASUREMENT OF GUST LOADS IN AIRCRAFT — J. TAYLOR

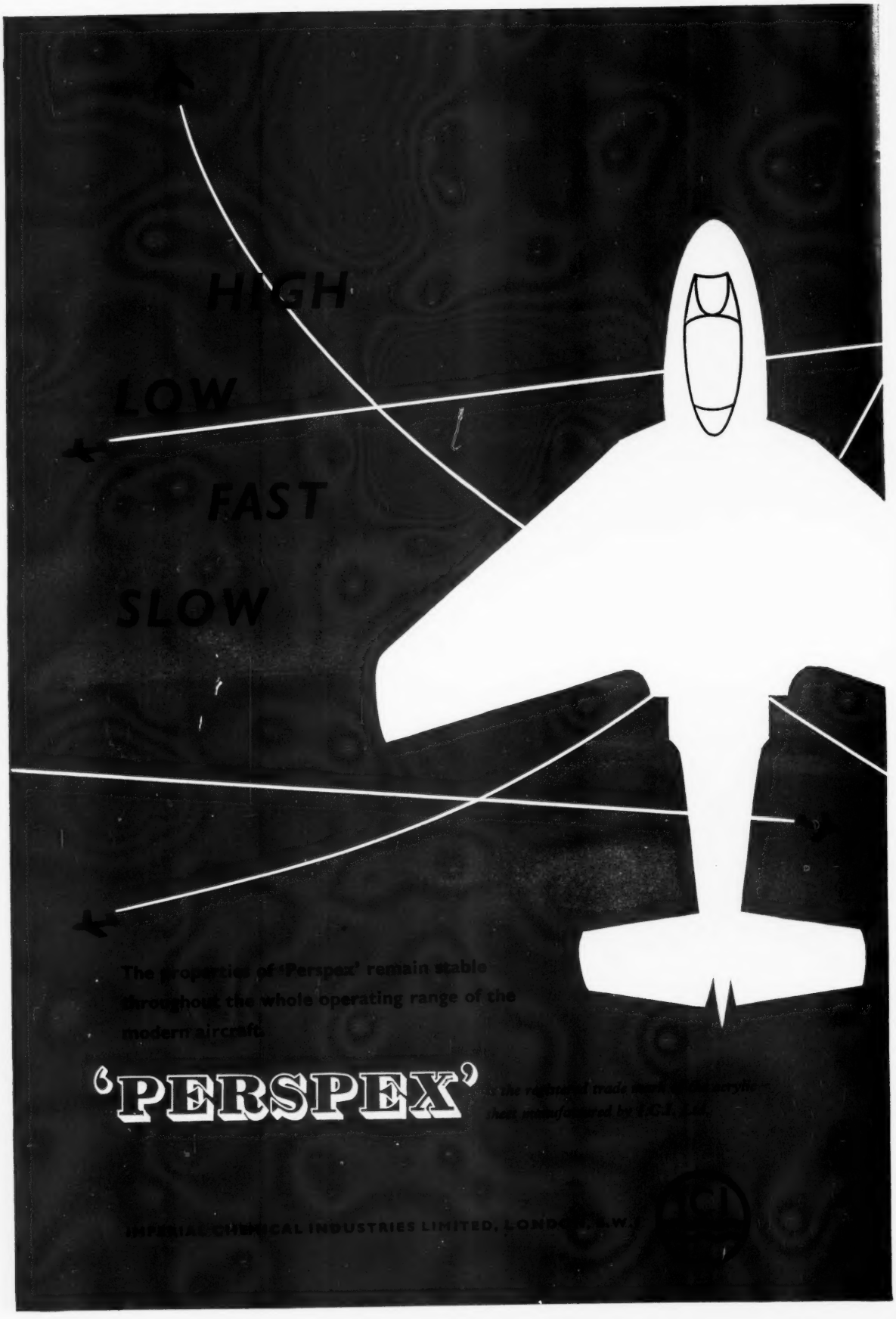
TEMPERATURE CONTROL OF JET-ENGINED AIRCRAFT — E. W. STILL

TECHNICAL NOTES
G. FORREST, K. W. GUNN AND A. R. WOODWARD: R. TATHAM: ANTHONY J. BARRETT

THE LIBRARY: REPORTS REVIEWS

TEN SHILLINGS MONTHLY

LONDON
4 HAMILTON PLACE W1


HIGH
LOW
FAST
SLOW
The properties of 'Perspex' remain stable throughout the whole operating range of the modern aircraft.
'PERSPEX'
is the registered trade mark of acrylic sheet manufactured by I.C.I. Ltd.
IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.1

Journal of

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

PUBLISHED MONTHLY AT

4 HAMILTON PLACE, LONDON, W.1

Telephone: Grosvenor 3515-9 *Telegrams*: Didaskalos, Audley, London

SUBSCRIPTIONS: £6 6S. 0D. PER ANNUM, POST FREE. SINGLE COPIES: 10S. 6D., POST FREE.

VOLUME 57 FEBRUARY 1953 NUMBER 506

CONTENTS

PAGE

Secretary's News Letter IX

Notices X

New Year Honours—Nomination of Candidates for Council—Election of Fellows—Honours—Institute of the Aeronautical Sciences—Members' New Appointments—Graduates' and Students' Section—Elections—Acknowledgments.

All-Day Discussion on Fatigue: See Leaflet enclosed.

Rex Pierson—An Appreciation and the Lessons of His Work — SIR A. H. ROY FEDDEN — 63

Measurement of Gust Loads in Aircraft — J. TAYLOR — 78

Temperature Control of Jet-Engined Aircraft — E. W. STILL — 89

Technical Notes 103

Fatigue Properties of Z-Section Test Pieces Completely Machined from an Aluminium Alloy Extrusion Conforming to D.T.D. 364B. G. FORREST, K. W. GUNN and A. R. WOODWARD.—An Application of Carpet and Lattice Plotting. R. TATHAM.—Bending of Some Common Beam Sections into the Plastic Range. ANTHONY J. BARRETT.

The Library 115

REVIEWS: Advanced Strength of Materials—Across the Space Frontier—Handbook of Supersonic Aerodynamics—Studies in Elastic Structures—Elements of Wave Mechanics—Climate and the British Scene—Observer's Handbook—Physical Aspects of Air Photography.

ADDITIONS TO THE LIBRARY REPORTS

All communications for publication in, and advertisements for, the Journal should be addressed to the Editor, Joan Bradbrooke, A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary, A. M. Ballantyne, T.D., B.Sc., Ph.D., A.F.R.Ae.S.

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless stated otherwise.

PRINTED BY THE LEWES PRESS (WIGHTMAN & CO. LTD.), FRIARS WALK, LEWES, ENGLAND, AND PUBLISHED BY THE ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, LONDON, W.1, ENGLAND.

THE ROYAL AERONAUTICAL SOCIETY

Overseas Divisions

AUSTRALIA

Chairman: Professor A. V. STEPHENS, F.R.Ae.S.

Hon. Secretary: W. ISBISTER, 19 Wallace Street, Burwood, Sydney, New South Wales. [A.F.R.Ae.S.

NEW ZEALAND

President: Air Vice-Marshal Sir ARTHUR NEVILL, K.B.E., C.B., A.F.R.Ae.S.

Hon. Secretary: T. T. N. COLERIDGE, The Shell Company of New Zealand Ltd., Box 2091, Wellington. [A.F.R.Ae.S.,

SOUTHERN AFRICA

President: JOHN NASH, A.F.R.Ae.S.

Hon. Secretary: E. A. BUNT, A.F.R.Ae.S., Dept. of Mechanical Engineering, University of The Witwatersrand, Milner Park, Johannesburg.

Branches in the United Kingdom

BELFAST

President: Rear-Admiral M. S. SLATTERY, C.B., F.R.Ae.S., R.N.(Retd.)

Chairman: C. P. T. LIPSCOMB, F.R.Ae.S.

Secretary: E. N. BRAILSFORD, A.F.R.Ae.S., Short Brothers & Harland Ltd., Queens Island, Belfast, N. Ireland.

BIRMINGHAM

President: G. FIRKINS.

Hon. Secretary: C. P. HOMES, A.R.Ae.S., 81 Peplins Way, Kings Norton, Birmingham, 30.

BRISTOL

President: A. E. RUSSELL, F.R.Ae.S.

Chairman: A. C. CLINTON, F.R.Ae.S.

Hon. Secretary: J. M. HAHN, Grad.R.Ae.S., Structures Dept., Aircraft Division, Bristol Aeroplane Co. Ltd., Filton, Bristol.

BROUGH

President: R. BLACKBURN, O.B.E., Hon.F.R.Ae.S.

Chairman: G. E. PETTY, F.R.Ae.S.

Hon. Secretary: F. A. WILKINSON, A.F.R.Ae.S., Blackburn & General Aircraft Ltd., Brough.

CHESTER

Chairman: K. G. HANCOCK, A.F.R.Ae.S.

Hon. Secretary: J. G. SHARP, A.F.R.Ae.S., Thornton Research Centre, P.O. Box 1, Chester.

COVENTRY

President: H. M. WOODHAMS, C.B.E., F.R.Ae.S.

Chairman: W. J. PETERS.

Hon. Secretary: C. T. SCULTHORPE, A.F.R.Ae.S., Sir W. G. Armstrong Whitworth Aircraft Ltd., Baginton, Coventry.

DERBY

President: LORD HIVES, C.H., M.B.E., F.R.Ae.S.

Chairman: A. G. ELLIOTT, C.B.E., F.R.Ae.S.

Hon. Secretary: C. L. HININGS, O.B.E., A.F.R.Ae.S., Rolls-Royce Ltd., Derby.

GLASGOW

President: Professor W. J. DUNCAN, F.R.Ae.S.

Chairman: T. B. LYON, A.F.R.Ae.S.

Hon. Secretary: A. W. BABISTER, A.F.R.Ae.S., Department of Aeronautics, The University, Glasgow, W.2.

GLOUCESTER AND CHELTENHAM

President: H. BURROUGHES, F.R.Ae.S.

Chairman: A. E. BINGHAM, F.R.Ae.S.

Hon. Secretary: C. E. HUTT, S. Smith & Sons Ltd., Bishops Cleeve, Cheltenham.

HALTON

President: Marshal of the Royal Air Force VISCOUNT TRENCHARD, Hon.F.R.Ae.S.

Chairman: Group Captain RAPLEY, A.F.R.Ae.S.

Hon. Secretary: Flying Officer E. S. STREET, A.F.R.Ae.S., Station Headquarters, R.A.F., Halton.

HATFIELD

President: Sir GEOFFREY DE HAVILLAND, C.B.E., A.F.C., R.D.I., Hon.F.I.Ae.S., F.R.Ae.S.

Chairman: R. H. T. HARPER, F.R.Ae.S.

Hon. Secretary: E. J. MANN, A.R.Ae.S., de Havilland Aircraft Co. Ltd., Hatfield.

HENLOW

Chairman: Squadron Leader D. McL. FERRIER, F.R.Ae.S.

Hon. Secretary: Flight Lieutenant D. J. COCKRELL, Grad.R.Ae.S. Engineer Wing, R.A.F. Technical College, Henlow, Bedfordshire. R.A.F. Technical College, Henlow, Bedfordshire.

ISLE OF WIGHT

President: Sir ARTHUR GOUGE, F.R.Ae.S.

Chairman: H. KNOWLER, F.R.Ae.S.

Hon. Secretary: D. J. HARDY, A.F.R.Ae.S., Saunders-Roe Ltd., Osborne, E. Cowes, Isle of Wight.

LEICESTER

Chairman: Wing Commander H. E. FALKNER, A.F.R.Ae.S.

Hon. Secretary: K. B. AYERS, A.F.R.Ae.S., 10 Spinney Rise, Birstall, Leicester.

LUTON

Chairman: F. S. LESTER, A.R.Ae.S.

Hon. Secretary: H. J. BROOKS, A.F.R.Ae.S., Percival Aircraft Ltd., Luton.

MANCHESTER

President: Sir ROY H. DOBSON, C.B.E., J.P., F.R.Ae.S.

Chairman: C. E. FIELDING, O.B.E., A.F.R.Ae.S.

Hon. Secretary: J. A. E. WATERFALL, 56 Manor Avenue, Ashton-on-Mersey, Cheshire.

MERTHYR TYDFIL

President: W. F. F. MARTIN-HURST.

Chairman: Dr. E. W. STILL, F.R.Ae.S.

Hon. Secretary: G. M. MAGILL, A.F.R.Ae.S., Teddington Controls Ltd., Cefn Coed, nr. Merthyr Tydfil, South Wales.

PORTSMOUTH

President: A. TOWNSLEY.

Chairman: G. H. M. TWYMAN.

Hon. Secretary: E. M. BELLAMY, A.R.Ae.S., Airspeed Ltd., The Airport, Portsmouth.

PRESTON

President: Sir GEORGE H. NELSON.

Chairman: D. L. ELLIS, F.R.Ae.S.

Hon. Secretary: J. C. KING, A.F.R.Ae.S., Aircraft Division, English Electric Co. Ltd., Warton Aerodrome, nr. Preston.

READING

President: Sir FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.

Chairman: E. W. GRAY, A.F.R.Ae.S.

Hon. Secretary: E. L. PEARSON, A.R.Ae.S., Handley Page (Reading) Ltd., The Aerodrome, Woodley, Reading.

SOUTHAMPTON

Chairman: Professor E. J. RICHARDS, F.R.Ae.S.

Hon. Secretary: H. C. SMITH, F.R.Ae.S., Vickers-Armstrongs Ltd., Supermarine Works, Hursley Park, Winchester.

WEYBRIDGE

President: G. R. EDWARDS, C.B.E., F.R.Ae.S.

Chairman: H. H. GARDNER, F.R.Ae.S.

Hon. Secretary: J. H. SINCLAIR, A.F.R.Ae.S., Vickers-Armstrongs Ltd., Weybridge.

YEOVIL

Hon. Secretary: L. A. LANSDOWN, A.F.R.Ae.S., Westland Aircraft Ltd., Yeovil.

Secretary's News Letter

February 1953

THE proposed change in the size of the JOURNAL was announced some months ago in a News Letter. That change has now been made.

All the opinions given to me have been very favourable; some, indeed, have been enthusiastic. I, too, think that the Editor has done extremely well a job which was by no means easy. On your behalf I wish to tell the Editor our thanks for the care and thought which have been put into this new JOURNAL, of which the Society can be justifiably proud.

The President gave a party for the Society Staff on 12th December, and it was enjoyed thoroughly by everyone. The Library was decorated with streamers and balloons, and a Christmas Tree added the final touch. Santa Claus made a welcomed appearance to the delighted surprise of both Staff and Guests. The "tempera" change but the "mores," in this case, remain the same. Thank you, Mr. President.

The Southampton Branch of the Institution of Production Engineers held a two-day Conference on the Production of Aircraft at the University of Southampton on Friday and Saturday the 19th and 20th December. I managed to attend only the first two lectures, one by Dr. A. E. Russell, Bristol Aeroplane Company, and the other by Mr. R. W. Walker, Gloster Aircraft Limited. There were many aircraft firms represented in the audience, as well as on the lecturing platform. It seemed to be a very useful "get together."

The Annual Dance of the Weybridge Branch was also held on the 19th December. I have little to say of this, for when it is said that it was up to standard, nothing further is required. At Weybridge the Branch President, Chairman and Secretary make up a good team, for they had organised well for our delight.

The Staff and I received many Christmas cards, and we wish to say how much they are appreciated. We send sincere, although belated, best wishes to all members of the Society for 1953.

On Monday 5th January I attended a Conference on "The Presentation of Technical Information." This was sponsored by the Communication Training Centre, a department of the British Association for Commercial and Industrial Education.

One of the speakers was Professor R. O. Kapp, who was instrumental in having this subject put into the final year curriculum of the electrical engineering students at University College, London, for it was found that the standard of report writing by graduates was lamentably low. A study group on the Presentation of Technical Information has been formed, and if any member of the Society is interested I could forward further information and particulars.

I have an affection for Chester and was very pleased to attend a Branch Meeting there on Wednesday 7th January. The Lecturer was Sir Vernon Brown, who spoke on "Aircraft Accident Investigation." The meeting was well attended and was held in the Grosvenor Hotel.

Before the lecture Mr. E. L. Bass gave a small dinner to the Lecturer and the Branch Committee.

The afternoon previous to the lecture I spent looking over Electro-Hydraulics, Warrington, under the guidance of Mr. K. G. Hancock, who is the Branch Chairman. I found the drop test of an undercarriage very interesting, although noisy. The wheels are spun vigorously, and the landing platform is a movable one. I was shown a film of a test taken with a high speed camera; it is remarkable how quickly the dropped spinning wheels come to rest. I was assured that there had been no burst tyres—yet. Of course, if one were to burst, the results would be fairly chaotic. For some time I have known of the macabre sense of humour of test engineers. Twenty odd years ago I visited a test house in Edinburgh and was told the same thing concerning a very large flywheel.

At the invitation of Mr. J. J. Dawson I visited the Thornton Research Centre of the Shell Petroleum Company. I found this extremely interesting. I was only able to see a small fraction of the Shell activities, but have promised myself another visit sometime.

Enclosed in this JOURNAL there is a leaflet concerning the holding of a Discussion on Fatigue on Friday 27th March at University College, London. Will those who intend to be present please fill in the form and return it to me as soon as possible.

The Anglo-American Aeronautical Conference is being held in London in September 1953. On Monday 14th September The Wilbur Wright Memorial Lecture will be given by Professor Nicholas J. Hoff, Head of the Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn. This will be followed by a Reception to members of the

Society and the delegates to the Conference. On Tuesday the Conference will begin, and the lectures will continue over the 15th, 16th and 17th September. Further details will be announced later.

The attention of Fellows of the Society is drawn to the announcement regarding the election of Fellows. If there are any queries about the status of any Member I shall be pleased to help.

A. M. Ballantyne

Secretary

NOTICES

An annual sum of £250 is available for premium awards, usually 15 guineas each, for papers published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

New Year's Honours List 1953

The following members were included in the New Year's Honours List:—

Knight Bachelor
Harold Roxbee Cox (*Fellow*)

Order of the Bath

C.B.
Acting Air Vice-Marshal H. P. Fraser (*Fellow*)

Order of the British Empire

G.B.E.
Lord Brabazon of Tara (*Fellow*)

C.B.E.
Captain K. J. G. Bartlett (*Associate Fellow*)

O.B.E.
Squadron Leader N. F. Duke (*Associate*)
Commander B. W. Galpin, R.N. (retd.) (*Companion*)

M.B.E.
Mrs. A. C. Douglas (*Associate*)
D. M. Jameson (*Associate Fellow*)

Queen's Commendation for Valuable Service in the Air
Captain A. M. A. Majendie (*Associate Fellow*)

Election of Fellows

The attention of members is drawn to the following extract from the By-laws:—

"Elections to Fellowship will be made annually by the Council and will be announced at the Annual General Meeting of the Society. Nominations will be initiated by the members of the Council or by any four Fellows of the Society. It is the duty of the Council to see that the honour is awarded only to persons who have attained a considerable degree of technical eminence in the profession of aeronautics."

Nominations initiated by any four Fellows of the Society should be received by the Secretary on or before *1st April 1953* to give sufficient time for the Council to consider them in time for announcement at the Annual General Meeting in May.

Nomination of Candidates for Council

The following is an extract from the By-laws:—

"The Twenty-one ordinary members (of the Council) shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes: Associate Fellow, Associate and Graduate.

"Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since their last election but they shall be eligible for re-election.

"Nominations of candidates for election to the Council must be received by the Secretary not later than *10th April* in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be Voters."

Nomination forms may be obtained on application to the Secretary.

Honours Awarded to Members

Mr. C. C. Walker (*Fellow*) has been made an Honorary Fellow of the Institute of the Aeronautical Sciences. Only one foreign Honorary Fellow is elected in each year by the Institute.

The President, Mr. George H. Dowty (*Fellow*) and Mr. P. G. Masefield (*Fellow*), Vice-President of the Society, have been elected Fellows of the Institute of the Aeronautical Sciences.

The James Watt International Medal for 1953

The Institution of Mechanical Engineers has awarded Sir Harry Ricardo (*Fellow*) the James Watt International Medal for 1953 for his contributions to knowledge of the fundamental principles of Internal Combustion Engines and the application of these principles to design and development.

Board of Studies of the University of London

Dr. A. M. Ballantyne (*Associate Fellow*) has been appointed a member of the Board of Studies in Aeronautical Engineering for 1953 by the Senate of the University of London.

Members' New Appointments

Douglas S. Cawser (*Associate Fellow*), formerly with British Overseas Airways, has been appointed a partner in Cawser & Company, Drawing Office Specialists.

Peter B. Clay (*Graduate*) has recently been transferred from Rolls-Royce Limited, Derby, to Rolls-Royce Montreal Ltd., to take up an appointment in the Technical Services Department.

Captain J. C. Kelly Rogers (*Associate Fellow*) has been appointed Deputy General Manager of Aer Lingus. He will continue as Head of the Technical Division of the Company with Headquarters at Dublin Airport.

Peter G. Lawrence (*Associate*), formerly Test Pilot, Blackburn and General Aircraft Ltd., has joined the Gloster Aircraft Co. team of Test Pilots.

G. G. Levy (*Associate Fellow*), formerly of the de Havilland Engine Co., has taken up an appointment with the National Research Council of Canada.

A. D. Marshall (*Associate*) has taken up a position with Canadair Ltd.

Frank Rawling (*Associate Fellow*) has joined the Design Staff of British Messier Ltd., Gloucester.

J. V. Roberts (*Associate*) has been appointed Assistant Designer, Short Bros. & Harland Ltd., Belfast.

Leonard Smith (*Associate Fellow*) has been promoted to Lecturer in the Mechanical Engineering Department of the Medway Technical College.

H. D. Strawson (*Associate Fellow*), who joined Bryans Aeroquipment Ltd. in June 1952, has been appointed to the Board of the Company as Production Director.

Graduates' and Students' Section

Annual General Meeting

The Annual General Meeting of the Section will be held at the Society, 4 Hamilton Place, W.1, on Wednesday 11th March 1953 at 7.30 p.m. Light refreshments will be available from 7 to 7.30 p.m., and the meeting will be followed by an aeronautical film show. Agenda:

(*i*) To consider and approve the Minutes of the previous Annual General Meeting.

(*ii*) To consider any business arising from these Minutes.

(*iii*) To receive the Report of the Committee on the activities of the Committee and of the Section during the past year.

(*iv*) To make recommendations to Council on the names of the representatives of the Section to serve on the Committee for the year 1953-4.

(*v*) To receive the Rules for the administration of the Section.

(*vi*) To discuss the future activities of the Section.

(*vii*) To consider any other business connected with the affairs of the Section.

Nominations for the Section's representatives on the Committee should be sent to the Hon. Secretary before 9th March, or may be handed in at the meeting. They must be signed by the candidate, proposer and seconder, who must all be Graduates or Students. The number of vacancies to be filled is nine, and if the nominations exceed this number, a ballot will be held at the meeting. Successful candidates' names are subject to confirmation by Council.

Members are reminded that it is desirable for the Committee to be representative of as many firms and colleges as possible.

Michael C. Campion, Hon. Secretary,
127 Kyverdale Road, London, N.16.

Institute of the Aeronautical Sciences for 1953

Charles J. McCarthy, Vice-President of United Aircraft Corporation, has been elected President of the Institute of the Aeronautical Sciences for 1953. Mr. McCarthy is a Fellow and Founder Member of the Institute.

Four other Fellows of the Institute have been elected to serve as Vice-Presidents: George W. Brady, Director of Engineering, Propeller Division, Curtiss-Wright Corporation; Clarence L. (Kelly) Johnson, Chief Engineer, Lockheed Aircraft Corporation; James S. McDonnell, Jnr., President, McDonnell Aircraft Corporation; Ernest G. Stout, Staff Engineer, Consolidated Vultee Aircraft Corporation.

Graduates' and Students' Section—Visit

A visit has been arranged to the "Daily Mail" printing works at Northcliffe House, and to the "Daily Herald" printing works at Odhams Press Ltd., on Tuesday, 17th March 1953. Both visits will begin at 9.30 p.m. and will last about two hours. Numbers are limited for each visit and early application should be made to the Honorary Visits Secretary of the Section, C. B. Redgate, *Graduate*, 83 Wandle Road, Morden, Surrey.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Charles Abell; Reginald Donahoe Ball; Andrew Dent Balmain (from Associate); Eric Melrose Brown (from Associate); Robert Brown; Dermot Mitchell Egan (from Associate); William Thomas Elson (from Associate); Henry Ronald Farmer; John Gibbons; Alfred Edmund Jefferson; John Jenkins; Barry Alaric Gault MacGowan (from Graduate); Denis William Peacock; Terence Maxwell Pullin; John Raymond Robinson (from Graduate); Frederick James Traven (from Graduate); Eric Enos Watts (from Graduate).

Associates

Denis Cressey; John Cyril Fell (from Graduate); Eric Douglas Hall; Arthur Leslie Howarth; Arthur Edward Maine; Frank William Richards Moody; William George Wright.

Graduates

Thomas Eric Barton Bateman; Roy Benstead; Brian Bethell; John Brenchley; Frederick Brown; Hans Anton Buchholdt (from Student); Michael David Clark; Richard Arthur Clarke (from Student); Alexander Campbell Craighead (from Student); Roland Dennett (from Student); Wilfred James Eggington; David John Foster; Douglas Percival Hart (from Student); Peter Malcolm Hughes; Eckart Lemberg (from Student); Peter John Mettam (from Student); Thomas Rogers; Anthony James Scarr; David Arthur Sharp (from Student); Leonard Thomas Smith; Michael Jordan Taylor (from Student); Tudor William Thomas (from Student); Kenneth William Watkins.

Students

William Kendal Allan; Ronald Ashford; James Scriven Bartlett; Barun Chandra Basu; John Barry Caress; James Ernest Cleaver; Olwyn Anthony D'Sylva; Alan William Elliott; Lionel Gordon Evans; George Antonio Edward Fielder; John Cyril Francis; Arthur Charles Fry; Amitabha Das Gupta; Robert Alfred James Jones; Brian Kaye Knight; C. S. Krishnamoorthi; Neil Vernon McEachern; George Edward McGowan; Michael Arthur Mansfield; Brian Murphy; Leslie Albert Nash; Bryan Edward Neave; Richard Easthope Needham; Raymond George Rough; Joseph Sacharin; Kenneth Douglas Sadd; John William Charles Sandford; Constantine Christopher Taliadoros; Eduardo de Beires Valle; Roger Boyd Walker; Jack Walters; Brian Scott Ward; Bruce Winston Weller; Rex Stephen Wilkinson; Albert Loxley Window.

Diary

LONDON

February 11th

GRADUATES' AND STUDENTS' SECTION. Production of Prototype Aircraft. W. Thorn. 4 Hamilton Place, W.1. 7.30 p.m.

February 12th

SECTION LECTURE. The Application of Integral Construction to Aircraft Design and Its Effect on Production Methods. E. Dixie Keen. 4 Hamilton Place, W.1. 7 p.m.

February 17th

SECTION LECTURE. Recent Developments in Gliding. A. H. Yates. 4 Hamilton Place, W.1. 7 p.m.

February 24th

GRADUATES' AND STUDENTS' SECTION. Viscount Operations. Capt. R. Rymer. 4 Hamilton Place, W.1. 7.30 p.m.

February 26th

MAIN LECTURE. New Materials and Methods for Aircraft Construction. H. J. Pollard. Institution of Mechanical Engineers, Storey's Gate, S.W.1. 6 p.m. Tea 5.30 p.m.

March 11th

GRADUATES' AND STUDENTS' SECTION. Annual General Meeting. 4 Hamilton Place, W.1. 7.30 p.m. Followed by an aeronautical film show, including the "S.B.A.C. Show 1952." Coffee 7-7.30 p.m. *See* Notice.

March 12th

MAIN LECTURE at **DERBY**. Some Aspects of High Performance Jet Aircraft. Sqdn. Ldr. W. A. Waterton, G.M., A.F.C. In the Rolls-Royce Welfare Hall, Nightingale Road, Derby. 6.15 p.m.

March 17th

GRADUATES' AND STUDENTS' SECTION. Visits to the "Daily Mail" and "Daily Herald" printing works. *See separate notice.*

March 19th

SIXTH LOUIS BLERIOT LECTURE. Making Commercial Aircraft Pay. General Guy de Merle. Institute of Mechanical Engineers, Storey's Gate, S.W.1. 6 p.m. (Tea 5.30 p.m.)

March 25th

GRADUATES' AND STUDENTS' SECTION. Convertible Aircraft. J. Shapiro, Dipl. Ing. 4 Hamilton Place, W.1. 7.30 p.m.

March 27th

FULL DAY DISCUSSION ON FATIGUE. At the Chemistry Lecture Theatre, University College, Gower Street, W.C.1. 10 a.m. to 6.30 p.m. *See* leaflet enclosed.

March 31st

SECTION LECTURE. Experimental Work on Boundary Layer Flow. W. E. Gray. In the Library, 4 Hamilton Place, W.1. 7 p.m.

BRANCHES

February 2nd

Derby—Colour Films. Presented by William Courtenay. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

Halton—Films. Branch Hut. R.A.F. Station. Halton. 6.45 p.m.

February 3rd

Bristol—Film Show. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

February 4th

Chester—The Design and Maintenance of Sparking Plugs. V. Martin Jones. Grosvenor Hotel. 7.30 p.m.

Southampton—Lecture by W. E. W. Petter, C.B.E. Institute of Education, University of Southampton. 7 p.m.

Weybridge—Branch Members. Members' Prize Lecture. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

February 9th

Halton—Powered Flying Controls. Wing Cmdr. D. H. Grundy. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

February 10th

Henlow—Power Plants for High-Speed Aircraft. A. D. Baxter. 163 Building, R.A.F. Technical College, Henlow. 7.30 p.m.

February 11th

Brough—Structural Problems of Advanced Aircraft. H. H. Gardner. Electricity Showrooms, Ferensway, Hull. 7.30 p.m.

February 11th

Hatfield—The War in the Pacific. Films and Commentary. William Courtenay, O.B.E., M.M. Senior Staff Mess, de Havilland Aircraft Co. Ltd., Hatfield. 6.15 p.m.

Weybridge—Film. Packaged Power. (Northern Aluminium Co. Ltd.) Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

February 12th

Glasgow—The Aiming of Aircraft Weapons. V. B. Smith. Royal Technical College. 7.30 p.m.

Isle of Wight—Aircraft Maintenance. H. Gordon. Club House, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

Portsmouth—Films. Technical School of the de Havilland Aircraft Co. (Portsmouth) Ltd., The Airport, Portsmouth. 6 p.m.

February 13th

Birmingham—Bird Flight. Captain J. L. Pritchard, C.B.E. Birmingham Chamber of Commerce. 7.15 p.m.

February 17th

Birmingham—Films. Shown by the Birmingham Aviation Club. The International Centre, Suffolk Street. 7 p.m.

February 18th

Bristol—The Impact of the Gas Turbine on Aero-Engine Production Methods. D. A. Fairnie. The Grand Hotel, Bristol. 7.30 p.m.

Coventry—Problems and Advantages of Propeller Turbine Aircraft. H. R. Watson. Wine Lodge. 7.30 p.m.

Reading and District—Rocket Propulsion and Interplanetary Flight. A. V. Cleaver. The Abbey Gateway Room, Abotts Walk. 7.45 p.m.

Diary

BRANCHES

February 20th

Leicester—Viscount Design. D. J. Lambert. The Lecture Theatre, Loughborough College. 7.15 p.m.

February 23rd

Halton—Ram Jet Propulsion. Flt. Ltd. R. C. Rogers. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

Henlow—Annual General Meeting. 163 Building, R.A.F. Technical College, Henlow. 7.30 p.m.

February 24th

Belfast—Constructional Trends and their Effect on Airframe Production. R. E. Harvey. New Hall, Kensington Hotel, College Square East, Belfast. 7 p.m.

February 25th

Hatfield—Debate—Subject to be announced. Senior Staff Mess, de Havilland Aircraft Co. Ltd., Hatfield. 6.15 p.m.

Southampton—Junior Prize Papers. Institute of Education, University of Southampton. 7 p.m.

Weybridge—Brains Trust. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

February 26th

Isle of Wight—Junior Branch Members. Members' Prize Lectures. Club House, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

March 2nd

Derby—Supersonic Propellers. A. C. Walker. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

Halton—Lecture by Jeffrey K. Quill, O.B.E., A.F.C., of Supermarine Works, Vickers. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

March 4th

Bristol—Development of the Bristol Proteus Turbine Engine. S. G. Hooker, O.B.E. Royal Fort Physics Laboratory, Bristol. 7.30 p.m.

Chester—A Radio Aid to Air Navigation. C. Powell. Grosvenor Hotel, Chester. 7.30 p.m.

March 9th

Halton—Films. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

March 11th

Brough—Airships. Lord Ventry. Electricity Showrooms, Ferensway, Hull. 7.30 p.m.

Halton—Visit to Vickers-Supermarine, Winchester.

Hatfield—Navigational Problems Associated with the Introduction of Comet Aircraft. Captain A. M. Majendie. Senior Staff Mess, de Havilland Aircraft Co. Ltd., Hatfield. 6.15 p.m.

Southampton—Can We Reach Mars? E. G. Burgess. Institute of Education, University of Southampton. 7 p.m.

March 12th

Derby—MAIN SOCIETY LECTURE. Some Aspects of High Performance Jet Aircraft. Sqdn. Ldr. W. A. Waterton, G.M., A.F.C. Rolls-Royce Welfare Hall. 6.15 p.m.

Isle of Wight—New Materials and Types of Aircraft Structure. H. J. Pollard. Club House, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

Portsmouth—Films. Technical School of the de Havilland Aircraft Co. (Portsmouth) Ltd., The Airport, Portsmouth. 6 p.m.

March 13th

Derby—Provisional date for Dinner-Dance.

March 16th

Halton—Branch Night. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

March 18th

Coventry—Some Aspects of Airline Flying from the Pilot's Point of View. Captain R. Rymer, B.E.A. Wine Lodge. 7.30 p.m.

Leicester—Helicopter Design Problems. A. H. Yates. Lecture Theatre, Loughborough College. 7.15 p.m.

Reading and District—Flight of Birds. Captain J. L. Pritchard, C.B.E. Abbey Gateway Rooms, Abotts Walk, Reading. 7.45 p.m.

Weybridge—Making Aircraft. P. D. Normanville. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

March 19th

Glasgow—Engine Development Flight Testing. Wing Commander T. H. Heyworth. Royal Technical College. 7.30 p.m.

March 21st

Birmingham—Annual Dinner. White Horse Hotel, Birmingham.

March 23rd

Bristol—Junior Members' Papers Competition. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

Halton—Junior Members' Night. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

March 25th

Preston—Some Modern Aspects of Production. Professor J. V. Connolly. The Assembly Hall, Technical College, Corporation Street. 7 p.m.

March 26th

Portsmouth—Annual General Meeting. Technical School of the de Havilland Aircraft Co. (Portsmouth) Ltd., The Airport. 6 p.m.

March 31st

Belfast—Rocket Propulsion and Interplanetary Flight. A. V. Cleaver. New Hall, Kensington Hotel, College Square East, Belfast. 7 p.m.

NEW PERFORMANCE DATA SHEETS

A third issue of Performance Data Sheets has been sent to all holders of complete sets.

The new sheets deal with the estimation of range, of take-off distance and of landing distance, instrument corrections and the braking thrust and windmilling drag of propellers.

The new price of complete sets, including the latest issue, is £2 11s. 6d. to members of the Society and of the Society of British Aircraft Constructors, and £4 11s. 6d. to non-members. These prices include postage and folder.

Annual Subscriptions

Members are reminded that their annual subscriptions became due on 1st January 1953. The rates are:—

	Home	Abroad
Fellows	5 5 0	4 4 0
Associate Fellows	4 4 0	3 3 0
*Associates	3 3 0	3 3 0
Graduates (aged under 26)	2 2 0	2 2 0
Graduates (aged 26 and over)	2 12 6	2 12 6
Students (aged under 21)	1 1 0	1 1 0
Students (aged 21 and over)	1 11 6	1 11 6
Companions	3 3 0	3 3 0
Founder Members	2 2 0	2 2 0

*Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).

Grade of membership.

New address (in block letters).

Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

Journal Binding

Self-Binder Cases

Self-Binder cases of the "Easibind" type are available from the offices of the Society. These binders are for members who do not have their Journals permanently bound, or who wish to keep their Journals together during the year for binding later.

These cases will hold 12 Journals which are kept in place by means of flexible steel wires. Journals can be inserted or withdrawn easily without damage, so preserving the contents for permanent binding later. The Journals will open flat at any page.

The binder is strongly made in durable dark blue leather cloth on stiff board covers and has gold lettering on the spine. The year is not blocked on the spine but there is a panel on which members who wish to use the binder as a permanent case can put the date.

The cost is 11s. 6d. each including postage and packing for either the size to fit 1952 and previous Journals, or for the size to fit the Journal from January 1953, which has been increased in size. Orders and remittances should be sent direct to the Secretary at the Offices of the Society and it is *important to state whether the old size or new size is required.*

Permanent Binding

There is no increase in the price of permanent binding of Journals. The prices are:—

1952 Volume (including packing and postage) 16s. 0d.
Previous Volumes (including packing and postage) 18s. 0d.

Journals, *with a note of the name and address of the sender,* should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the offices of the Society.

Acknowledgments

The Council acknowledge with thanks the return of back numbers of The Journal from M. J. Atkinson, Esq., *Associate;* Sir Vernon Brown, *Fellow;* Wing Commander D. M. Egan, *Associate Fellow;* H. C. Newton, Esq., *Associate Fellow;* A. Rattle, Esq., *Associate Fellow;* and C. F. Uwins, Esq., *Fellow.*

Journal of The Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 57 FEBRUARY 1953 NUMBER 506

Rex Pierson
An Appreciation and the Lessons of his Work

by

Sir A. H. ROY FEDDEN, M.B.E., F.R.Ae.S.

The 860th Lecture to be given before the Royal Aeronautical Society was held under the auspices of the Weybridge Branch on 12th November 1952. Mr. G. R. Edwards, C.B.E., F.R.Ae.S., Vice-President of the Society, and President of the Weybridge Branch, welcomed the many distinguished visitors. He explained that it was an important occasion because not only was it the first Main Lecture to be given at the Weybridge Branch, but it was the first of a new series of lectures, to be known as the R. K. Pierson Memorial Lecture, which would be given annually as Branch Lectures.

Mr. G. H. Dowty, F.R.Ae.S., President of the Society, taking the Chair for the rest of the meeting, congratulated the Weybridge Branch on having the foresight to initiate what he believed was the first Main Lecture of the Royal Aeronautical Society commemorating one of their great aeronautical engineers. Sir A. H. Roy Fedden, M.B.E., F.R.Ae.S., who was to give the first Lecture of the new series, was well-known to them all.

PART I

I CONSIDER it a great privilege to have been chosen to give the first Rex Pierson Memorial Lecture, as not only is he an outstanding figure in British Aviation, but he was also one of my close friends.

Reginald Kirshaw Pierson was born in February 1891 at Fransham, Norfolk, his father being the rector there. He was educated at Felsted School. On leaving he was destined to enter the Bank of England, but at the last moment, mainly due to the untiring efforts of his mother, he was allowed to follow his natural bent, and take up engineering instead.

In 1908, therefore, at the age of 17 he entered the Erith Works of Vickers Ltd., as an engineering pupil-apprentice, passing through the various departments and, while there, taking his Bachelor of Science Engineering degree the hard way, from evening classes. When he was out of his time, he took a job with the Vickers Company in their newly-formed Aircraft Division as technician under A. R. Lowe. He learned to fly at Brooklands in 1913, his Aero Club Certificate being number 660.

Rex Pierson.

He was elected a Fellow of the Royal Aeronautical Society in 1926, and received the Society's Taylor Gold Medal in 1928 for a valuable paper on "The Use of the Wind Channel for Performance Prediction." He served on Council for several years, was a Vice-President in 1945, and was also on a number of the Society's committees, as well as those of other allied technical institutions.

From its inception he was a member of the Society's 1941 Advisory Committee to the Minister of Aircraft Production. Personal contacts I had with Sir Stafford Cripps during this time, enabled me to appreciate the high regard he had for Rex Pierson's work on this committee, which did valuable work during the 1939-45 War.

Rex Pierson was three times decorated for his services to the country, receiving the M.B.E. in 1919, the O.B.E. in 1941, and the C.B.E. in 1943. He was elected a Special Director of Vickers-Armstrongs in 1938.

Referring again to the initial stages of his career; in 1914 he became Chief Technician of the Aircraft Division of Vickers and, among other jobs, he was employed on the design and development of the series of well-known machines of the First World War, known as the Vickers Gun-bus.

FIGURE 1. The Vickers Vimy before the start of the first flight to Australia, on 12th November 1919.

It was in 1917 at the early age of 26 that he became Chief Designer of the Vickers Aircraft Division, chiefly I understand at the instigation of Capt. Peter Ackland, and was put in complete charge of the design office at Basil Street, Knightsbridge, building up a considerable war-time staff there. Early in 1919, the London drawing offices were shut down, and selecting a small nucleus of the most promising staff at Knightsbridge, Rex Pierson moved them down to the Vickers Aircraft Works on Brooklands Track, and from thence onwards Weybridge was his headquarters.

From this date until 1945 he remained Chief Designer to the Company, and was responsible for the design of the long series of successful Vickers aircraft between the two wars. His staff grew from about two dozen immediately after the First World War, to over 500 at the end of the Second World War, when he handed over the post of Chief Designer to George Edwards, and became Chief Engineer of the whole Vickers-Armstrongs Aviation Group.

It is unusual for a man to reach such eminence while remaining in the service of one company throughout his whole working career. He served the Vickers Company for just on 40 years, with outstanding success and unstinting loyalty. He played a profound part in the build-up of the Vickers aircraft organisation, in fact, for many years, he was Vickers Aviation, and was accepted as such by the Air Ministry, the Royal Air Force, the Aircraft Industry, and technicians both at home and abroad. A small point worth noting—he was seldom spoken of as Pierson, he was always Rex Pierson, or Rex to his immediate colleagues and friends, and R.K.P. to the rest.

FIGURE 2. The original Vickers Viking.

This is a brief account of his 40 years distinguished career and consecrated service to British Aviation, and I would like now to mention the 36 basic Vickers aircraft designs, with over 140 variants, which he inspired and select a few for description.

The first design for which he was entirely responsible was the Vimy bomber, with two Rolls-Royce Eagle engines, designed in 1917 immediately after he became Chief Designer, and produced from scratch to first flight in under six months. It was ordered in quantities and destined for the bombing of Berlin, but arrived too late in production to be actually operational in the First World War. The Vimy, however, proved itself to be a first class machine and immediately after the war was produced in various forms with notable success, including ambulance, commercial and transport versions. It earned undying fame when Alcock and Brown made the first direct non-stop crossing of the North Atlantic in 1919 in under 16 hours. It is extraordinary how little this unique effort was appreciated at the time, and how soon forgotten at home and abroad.

FIGURE 3. The Vickers Virginia.

I understand that R.K.P. was responsible for supervising the calculations in connection with this historic flight, no mean undertaking in those days when so little was known about the subject.

In the same year the Vimy made the first flight from England to Australia, and in 1920 another Vimy achieved a similar success to South Africa. Thus the Vimy, with three record firsts to its credit, must be considered a classic landmark in British Aviation.

Figure 1 was taken exactly 33 years ago—on 12th November 1919. It shows the Australian Vimy shortly before the start of its record flight. Rex Pierson may be seen on the right, then the Brothers Ross and Keith Smith, the pilots, Maxwell Muller, the Works Superintendent at Vickers, Weybridge, and Harold Perrin, Secretary of the Royal Aero Club. Possibly someone may recognise some of the others.

The commercial version of the Vimy had a nose wheel and four-wheel undercarriage, and generally good lines for its time. One of this type, named the City of

London, gave excellent service on the London-Paris route for more than three years.

Soon after the 1914-18 War R.K.P. produced the original Vickers Viking, an amphibian with a Napier pusher engine and for its vintage, a clean, workmanlike job. It won the Air Ministry £10,000 Competition for Amphibians in 1920 and a number were made. A licence to manufacture this machine in Canada marked the birth of the Canadian Vickers Company. Fig. 2 shows the actual machine on which, I believe, Alcock, of Atlantic fame, unfortunately lost his life, when flying to the 1921 Paris Salon. He made an emergency landing in France in foggy weather quite successfully, but did not see an obstruction in the field, and the aircraft turned over.

Then followed the Virginia, Victoria and Valentia series, all twin-engine biplanes. This was a very successful family and was used for a number of rôles, including bomber, troop carrier, ambulance and military transport. Several hundred of these machines were ordered in different versions, with various engines. These aircraft carried on as the mainstay of the R.A.F.

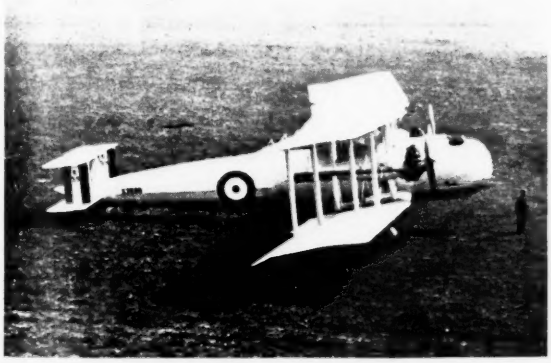


FIGURE 4. The Vickers Valentia.

for these widely varying purposes well into the 1930s, and were employed in many parts of the Empire, including India and the Middle East. They built up a great reputation for reliability and good service, and came to be known in the Royal Air Force as the "married man's" machine. Victorias were used for the withdrawal of more than 600 people from the British Legation during the Afghanistan Rebellion at the end of 1928, which included some hair-raising flights with very heavy loads, over impossible terrain. The Valentias made similar successful evacuations of civilians in 1939, and in fact, examples of this long series were in commission for the R.A.F. up to the beginning of the 1939-45 War.

Figure 3 shows the Virginia with one of the first rear turrets, and Fig. 4 the Valentia.

In the twenties, the Vickers Company took the licence for the French Wibault, a high wing all-metal monoplane fitted with Bristol Jupiter engine, employing a form of metal construction somewhat reminiscent of the German Junkers. This machine was produced in series for sale abroad, and might be said to be Vickers'

FIGURE 5. The Vickers Viastra all-metal civil monoplane.

first serious entry into all-metal construction. In 1924 Harris Booth joined R.K.P. to assist in producing the first all-metal Vickers aircraft, and there followed the Viastra, Fig. 5. This was a clean, high wing, all-metal civil machine with single, twin-engine and tri-motor editions, which had Townend cowling, complete exhaust system, spats on the wheels, and an all-moving tail unit. The spars were of the Vickers wandering web type, which consisted of two duralumin channels united by a light alloy plate riveted alternately to the fore and aft lips of the channels. There was also the Vellore (Fig. 6). The twin-float edition has been chosen to illustrate the versatility of the aircraft designer in those days. The Vellore was actually made as a single, and twin-engine, landplane, as well as a float machine. These are typical examples of Vickers' research into all-metal construction in the late twenties. This new technique for what, in those days, was a startling saving in weight, together with the lighter power plants which became available about this time, undoubtedly contributed in no small measure to the long life of the Virginia and Victoria family. The lessons learned at this period further stimulated R.K.P.'s interest in metal, and made him very weight-conscious.

About 1926 R.K.P. designed the Vespa, a high aspect ratio, staggered, metal biplane, again incorporating the wandering web spar construction, and fitted with the Bristol Jupiter engine. It was never produced in series for the Air Ministry, but a number were sold to Ireland and Bolivia. In fact, it was one of the last production models for Bolivia which was taken in 1931 and used for the Altitude Record which was established in 1932 by Cyril Uwins (Chief Test Pilot of the Bristol Company) with a Bristol engine. Fig. 7 shows R.K.P., Cyril Uwins and myself, in front of the record-breaking machine.

R.K.P. was not very enthusiastic about four-engine bombers, but in the late 1920s he produced the Vickers

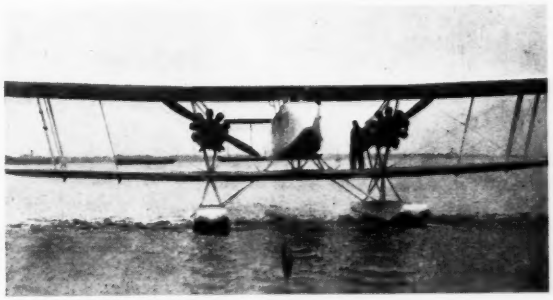


FIGURE 6. The Vickers Vellore.

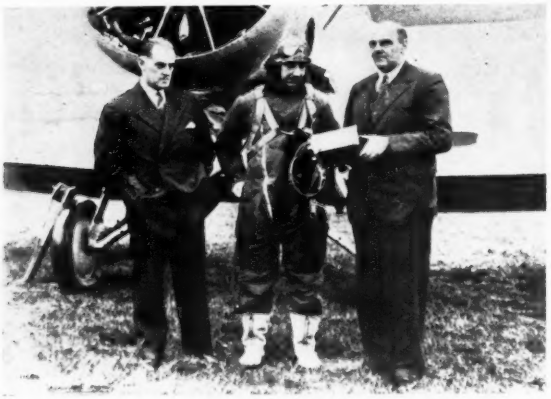


FIGURE 7. (*Left to right*): Roy Fedden, C. F. Uwins and R. K. Pierson in front of the Vickers Vespa in which Captain Uwins set up an Altitude Record of 43,976 ft. in 1932.

FIGURE 8. The Vickers 163 bomber.

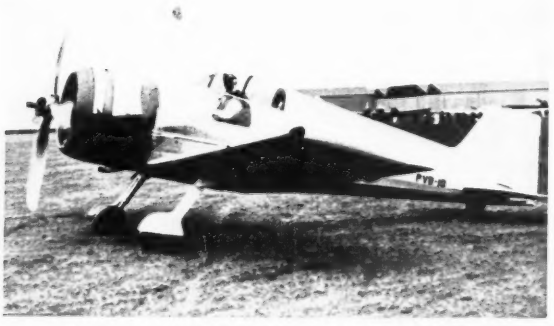


FIGURE 9. The Vickers Venom single-seat fighter.

FIGURE 10. The Vickers Vildebeest torpedo bomber.

163 heavy bomber with four Rolls-Royce engines in two tandem nacelles (Fig. 8). It was a really big aircraft for those days, and performed well. It had an all-moving tail unit, the top tailplane being used as an elevator, and the lower tailplane for trim. I am not sure why this machine did not go into production but I think it was a question of economy on the part of the Government, rather than any defect in the aircraft.

Another promising type which also did not go into production was the little Venom fighter with Bristol Aquila engine, shown in Fig. 9. The two-pitch de Havilland propeller, retractable undercarriage and long N.A.C.A.-type engine cowling will be noted for the first time. This machine is particularly interesting at the present time, because it was an early and successful attempt to break away from the conventional fighter specification in favour of a lighter aircraft and smaller engine. I think it would be correct to say that this machine failed to go into production because the Bristol Company was unable to manufacture the Aquila, due to pressure of other work.

The Vildebeest, a difficult specification, was started in 1927 and went into production in 1930. In various editions, and with different marks of Bristol engines, it was produced in hundreds and saw much service both at home and overseas. This aircraft successfully filled a large variety of difficult rôles for the R.A.F. until 1939. Fig. 10 shows the torpedo bomber version of the Vildebeest. About 1930 the Vellox appeared and was used for a number of purposes, including cargo-carrying, by Imperial Airways. Fig. 11 shows a close-up of this machine. The neat engine installation and wide undercarriage are interesting developments.

In the early 1930s the Air Ministry issued a new specification for a general purposes aircraft called G.4/31. This was keenly contested, and eight different prototypes were produced by various firms. Vickers won the competition with a biplane (Fig. 12), but pressed home to the Air Ministry the greater merits of the Wellesley, a mid-wing monoplane, a private venture built to this specification, which was eventually selected for production.

In 1930 B. N. Wallis joined the Weybridge design team. Previously he had been in charge of the design

FIGURE 11. The Vickers Vellox general purposes civil biplane.

FIGURE 12. The Vickers G.4/31 general purposes biplane.

FIGURE 13. The three long-range Vickers Wellesleys.

of the airship R.100 at the Airship Guarantee Company, a subsidiary of Vickers. He became Chief Structural Engineer at Weybridge, and was thus able to bring his unrivalled experience of light airship structures to the problem of aeroplane construction and, as a result of his investigations, he produced the well-known geodetic principle, which was first applied to the Wellesley.

The Wellesley, with Bristol Pegasus engine, was manufactured in considerable numbers and was used successfully by the R.A.F. right up to the early days of the 1939-45 War. This machine set up the World's Non-Stop Long Distance Record of 7,162 miles in 1938, a record which has been beaten only comparatively recently. Fig. 13 shows the three long-range Wellesleys on a practice flight.

The Air Ministry, in the early thirties, issued the B.9/32 Bomber specification which was the cause of a good deal of technical surmise, as well as political discussion, at the time and it was a number of years before the type came to fruition. Fairly promptly, Vickers produced a prototype for this competition which was a mid-wing monoplane, using the Wallis geodetic construction. It was remarkably clean for a heavy bomber of those days, and gave an extremely good account of itself on test. The general internal layout and turretry, however, had not been designed into the original prototype, and there was a considerable period of development, modifying the initial design to meet modern bombing operational requirements. R.K.P. paid his first visit to the United States of America about this time and was duly impressed with the big strides made there in civil types; he also visited Mildenhall in October 1934 for the start of the McRobertson Air Race to Australia and, in company with other members of the Aircraft Industry, was undoubtedly influenced by an event which has proved to be an important milestone in British Aviation.

The Wellington eventually emerged in production form at the end of 1937 and unquestionably did more than any other design to enhance Rex Pierson's reputation. When war broke out in 1939 there were six operational squadrons, and some of these took part in the first offensive raid of the War—on the Kiel Canal in September 1939. The Wellington had an excellent bomb load and range at the time it came out, and preserved its youth throughout the 1939-45 War. In fact, Wellington trainers are operating successfully in the R.A.F. today. The Wellington was produced in no less than 18 different types, with various Bristol engines. It has always looked an imposing, up-to-date machine, particularly from the air.

The Wellington played an important part in the first three to four years of the Second World War and became affectionately known as the "Wimpey" by the R.A.F. crews, and was regarded as one of our most satisfactory and reliable bombers during that vital period. Over 11,000 were produced, and 5,000 were put back into service after repairs—a wonderful record. It proved eventually to be a good manufacturing job, and the way the Chester and Blackpool shadow factories got going on production was an outstanding accomplishment. At one period, between 300 and 400 Wellingtons a month were being produced by the Vickers group.

At first the Achilles heel of the Wellington appeared to be a simple way of attaching the fabric, which was necessary with geodetic construction; ultimately, an entirely satisfactory solution was found, and this feature played an appreciable part in weight-saving.

Figure 14 shows the first Wellington prototype being man-handled over the bridge from the works to

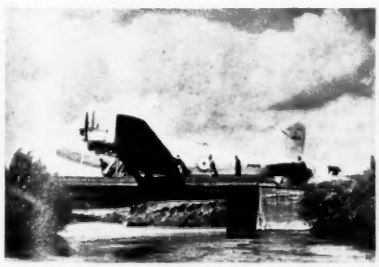


FIGURE 14. The first prototype of the Vickers Wellington.

FIGURE 15. The first production model of the Wellington.

FIGURE 16. The Wellington with Bristol Hercules engines.

FIGURE 17. The Wellington equipped for dealing with magnetic mines.

Brooklands aerodrome, and Fig. 15 a similar view of the first production machine. A slight change will be noted in the fin and rudder units and there are nose and tail turrets. The Wellington I.C. production model used Frazer Nash turrets. Fig. 16 shows the Hercules Wellington. Fig. 17 is of the special Wellington variant officially called D.W.I. (Direction Wireless Installation, a security name), which dealt successfully with the magnetic mine menace.

George Edwards could tell you much more about the details of this job, as, if I remember correctly, he was in charge of this whole project. I believe the large circular ring had a magnetic coil inside, which was energised from a Ford V.8 car engine in the fuselage. On the first occasion the device was operated at too close quarters to the mine, and I believe the ensuing explosion blew off most of the rear turret and tail of the Wellington, but the machine got home safely.

The Warwick (Fig. 18), a large edition of the Wellington design, but an entirely new aircraft with an all-up weight of 45,000 lb., followed in production towards the latter end of the war. This machine was designed to Air Ministry specification B.1/35, and took rather a long time to come to fruition, as it started life with two Rolls-Royce Vulture engines, changed to American engines for a time, and finally employed Bristol Centaurus engines. Eventually more than 800 Warwicks were built, and gave excellent service, chiefly for Coastal Command, for submarine detection, and air-sea rescue. Initially there were some problems on fabric covering, and certain rudder lock troubles, until a dorsal fin modification was added. On this machine, perhaps R.K.P. handicapped himself by retaining the twin-engine solution too long, but Vickers were held up by lack of delivery of suitable production engines. I know he put up a four-engine Merlin edition, but was not allowed to make it.

Towards the end of the Second World War the

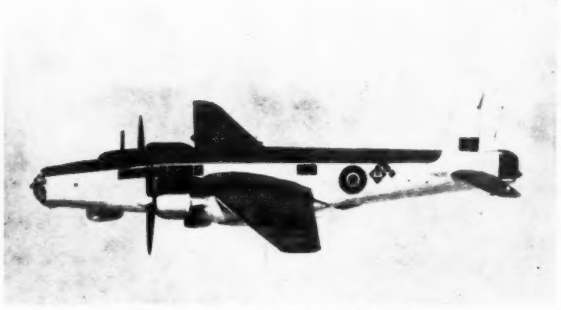


FIGURE 18. The Vickers Warwick.

FIGURE 19. The Vickers Windsor four-engine heavy bomber.

design team led by R.K.P. produced the Windsor, a high-wing heavy bomber with four Rolls-Royce Merlin engines with four separate landing wheels under each nacelle (Fig. 19). This machine had a 20 per cent. thick wing, with a special form of geodetic construction employing pre-tensioned wire-impregnated fabric covering. This aircraft was discontinued with the cessation of hostilities. Higher wing loadings, and the demand from civil operators, scrapped fabric and necessitated skin coverings in the future.

R.K.P. inspired the design team to get off the mark quickly after the war on a civil type, and Vickers produced the Viking. The prototype of this machine was produced in the summer of 1945, and although reminiscent of the Wellington, it was an entirely new aircraft with metal skin covering, and civil type Hercules engines. It has done yeoman service for British Civil Aviation as well as in other parts of the world, and is still in full use today. Fig. 20 shows a Viking of the King's Flight.

The Viking was followed quickly by the Valetta, a military edition with six different rôles as a troop carrier, freighter, ambulance, glider tug, paratrooper, and supply-dropping type. Altogether several hundred Vikings and Valettas were produced immediately after the war, and filled a very useful gap.

In 1946 R.K.P. initiated, with the Vickers design group, the basic foundation of the four-engine propeller-turbine civil transport, the Viscount. He was taken ill early in 1947 and was away from the works for some time. His recovery was never complete and he died in January 1948 at the early age of 56.

Such is the record of R.K.P.'s work with this pre-eminent list of outstanding successes.

1. The first machine to fly the North Atlantic non-stop, in 1919.
2. The first machine to fly from England to Australia, in 1919.

FIGURE 20. The Vickers Viking.

3. The first machine to fly from England to South Africa, in 1920.
4. The winner of the World's Altitude Record, 43,976 ft. in 1932.
5. The winner of the World's Non-Stop Distance Record of 7,162 miles in 1938.
6. The designer of the Wellington, one of the most successful British bombers of the Second World War, and produced in 18 different editions for various rôles.
7. The leader of the team responsible for the first successful post-war British air liner, the Viking, used exclusively in the King's Flight.

PART II

Rex Pierson employed a good many Bristol engines on his various designs between the two wars. In fact, for over 20 years I saw a great deal of him, more than any other aircraft designer, and collaborated with him on a number of these installations. During this period we had many meetings together and, with his immediate design colleagues and a small group of my own people, we built up a never-to-be-forgotten partnership between Vickers and Bristol which was most successful.

Naturally everything was not always smooth going, and we had our disagreements and, in fact, our battles, as was inevitable in the pioneering of the development of such a long line of new aircraft. I can say, however, that I never remember R.K.P. losing his temper with me, or in fact with any of his staff in my presence, although rumour had it that he was sometimes a bit severe with them alone afterwards. If Rex Pierson knew you and trusted you, he was a grand person to work with, and without doubt his handling of such situations and technical discussions was masterly. He was always glad to see us when we came up to Weybridge and would break off whatever he was doing to receive us. But he invariably had one standard formula directly we got into his office, which used to cause us some amusement preparing for it, on the way up from Bristol in the car; it was to the effect that Bristol engines were no good, were down in power, and were going up in weight, and fuel consumption.

I think we enjoyed these outbursts, as there were so many good lessons to be learnt from them. Basically he was always constructive and, if we listened to his point of view, we invariably arrived at a satisfactory conclusion and he would generally end up by some such remark as: "Well! I suppose we shall have to go on using Bristol engines," or, "I wish other engines were as good as yours." R.K.P. was at times a hard task master for an engine maker, but a most loyal and valuable friend if one had the sound sense to listen to him.

This collaboration worked so well that certain of his staff used to pull his leg, and say that no engine would work in Vickers aircraft but Bristols, which in a way may well be true, inasmuch as an aircraft designed for a certain type of piston engine seldom gave such a good account of itself when changed to another geometric form of engine. This does not hold good for the present-day turbine, as different makes of engine for a given duty often look, externally, almost identical.

We were both keen on fly fishing, and between the two wars had several holidays together, fishing on the Hampshire Test, in Wales and in Norway. We had some splendid times, and I had a good opportunity of studying R.K.P.'s characteristics in an entirely different setting, and noted certain of the same qualities, as in his work. For instance, his patience, calm persistence on a job, unselfishness to his friends, and general kindliness and good fellowship.

Three little personal touches which I call to mind. I am sure his staff would agree with me that you could usually get a decision out of him. If you put alternative schemes to him, he would consider both carefully and after a while point to one and say, "That will be all right, I think you'll find," and it generally was!

He wore a gold ring which, when absorbed in discussion, he would spin on his finger, or move it up and down rapidly, and when very deep in thought he would take it off and spin it on the table like a top. On one of our trips to the Paris Salon I have been reminded that, while sitting at a table in a well-known cabaret restaurant, he did his spinning trick with his ring while talking, and it escaped into the crowd of dancers, but was eventually recovered intact.

He was a fast car driver, but not dangerous, in spite

FIGURE 21. River repair work in Wales.

FIGURE 22. Fishing in Norway.

of carrying on long and involved technical discussions most of the time. But he was most unlucky about having small breakdowns, generally when it was dark and raining hard. When these did occur, there were seldom any tools in his car that would work. This was a fairly regular cause of argument between us.

He was a fine big man, a good deal taller than myself, and it was always a surprise to see him emerge from the Baby Fiat, and generally a cause for amusement when the two of us drove off in it.

He looked particularly distinguished in full evening dress, with very long tails. One wet night when driving up to London in evening dress to attend a formal function he had a puncture on the Bentley. He spread a rug carefully on the road upon which to lay out his tails, before bending down to change the wheel; unfortunately a passing car went over them, while they were spread out on the rug, and the ensuing situation can be better imagined than described.

I have two pictures of him I would like to show.

It was necessary for us to do quite a bit of river repair work in Wales to prevent floods from eroding the banks and destroying the salmon lies. This job chiefly fell to my lot, and Fig. 21 shows R.K.P. and myself dragging a log towards the river, for this job. I leave you to judge who was doing the work. Fig. 22 shows R.K.P. in Norway with John Howlett, of Wellworthy Piston Rings, after a good morning's sport.

PART III

So far I have endeavoured to give a brief factual account of R.K.P.'s most important achievements. What were the main characteristics of the man which made for this success? No human is ever infallible, least of all an aircraft engineer, and I am sure that R.K.P. would be the first to admit this and would wish me to say what I think, in an endeavour to help those that follow after him to carry on his great tradition in the Vickers Group, and to benefit not only from his success, but also from his mistakes.

I would say that some of the chief characteristics which contributed to his success were his absolute integrity, his capacity for taking immense pains, his open mind, and his willingness to listen to criticism and to take advice.

He was not only a big man in physical stature, but also in many other ways. He was friendly, almost royal in his approach, but always dignified. I have seen him in action with his staff, with distinguished foreigners, and with Ministers of the Crown; at such times he was a man of few words, quiet, and outwardly calm, in what he had to say, but he generally managed to get over his point. When need be, he was able to say things—sometimes quite hard things—in an unobtrusive, telling way, which many others could not do.

I believe I am right in saying that there must be very few indeed of the considerable number of people, over a period of just on 40 years, that passed through his hands, who would not say that there was an innate decentness in all his dealings with them. There was a kindliness but firmness, and generally speaking people liked working for him. He was a grand man in a team, and undoubtedly he was a great leader, but always with the gloved hand.

Early in his career Vickers had a private wind tunnel, and consistently he made practical use of it. Throughout his whole career he sponsored the laying down of larger and more powerful tunnels by his company, as progress demanded them. He had a balanced appreciation between the scientific and purely practical approach to aircraft design and manufacture, which was a great asset to him and his firm, and which was extremely rare 25 years ago. Aircraft designers and particularly aircraft firms were very secretive in the early days. Rex Pierson was always willing to discuss what he was doing with people he trusted; he would invite competitors to come and see his work in a way that was quite exceptional, as he felt that he would gain more than he lost by having their criticisms, and his firm were sensible enough not to oppose this enlightened outlook.

We of the engine fraternity used to be somewhat sceptical about the way some aircraft firms produced their drawings in the early days, but I was always appreciative of the way R.K.P. turned out his design material, and the care he took to see that components could be produced in the shops. The presentation of his reports was always first class. They were clear, short and to the point, and the English was good.

In close conversation he had the ability to express himself clearly on a technical subject, and whether talking to the managing director or to a junior draughtsman, he had that same open approach, entirely free from affectation or pretence.

He seemed always at home in his drawing office and would take me to the boards of one of his most senior or junior people, as the case demanded and, with equal facility, present his case.

I appreciate that it was far easier for a chief to do this 15 years ago than today, but I must admit that it was most convincing and enabled him to get the best response from his assistants.

He stuck to his job throughout his whole working career and had very few interests outside his family and fishing. He was extremely loyal to the firm for whom he worked, to the people who worked for him, and to his friends, and was always the first to give credit to anyone for initiative or the production of a new idea.

He was reticent and retiring and absolutely unswollen-headed at all times in his professional life, in fact, I think he was retiring to a fault and I sometimes told him so. He was entirely free from all business jealousy and lust for power; he was distinctly bored with this complex side of life in an up-and-coming industry, and preferred to be left alone to get on with his job.

We would have liked him to take a more prominent part in the Royal Aeronautical Society, but he would not do so. He was not a good public speaker, and off his own home pitch, I do not think was at his best controlling an outside committee. He was not keen on

taking part in technical discussions or attending lectures, and would always rather go home in the evenings, and be with his family. In a friendly way I used to pull his leg about this. For some years I tried to get him to come to America, and when eventually he did go he returned much impressed.

I think he may have been inclined to dwell in the present, and at times was willing to let somebody else pull the chestnuts out of the fire, which in the Aircraft Industry may not always be a bad thing for one's firm, as long as it does not occur too often. He was always keen and realistic, however, about finding a practical solution, and was ever ready with his sound engineer's approach and considerable ingenuity to face up to a problem on the floor of the shop. I think it might fairly be said that he was definitely more interested in the large aeroplane of his day, and did not bother very much with the small types.

I have heard some criticism that he kept too much to the centre of the road, and that some of his designs were not as clean aerodynamically as they should have been. I do not think that this criticism was justified as, until the later stages of his career, when he produced the Wellington which was a world beater, Rex Pierson was in command of Vickers' technical side at a very difficult formative period in aircraft design. He had a great responsibility to keep the production side of his firm going, while he was designing what were in those days, large machines, required to meet difficult, heavy load-carrying Government specifications, at a time when the powers-that-be were very conservative about sticking to biplanes, fixed undercarriages, and fixed pitch propellers.

Also, his aeroplanes had to operate from small grass aerodromes and, for the most part, he was not served with sufficient power by the engine makers. He always favoured light wing loadings and high aspect ratios, which paid good dividends. He was not a subscriber to the adage " that which looks right, is right," and was interested mainly in producing a sound aeroplane to do the required job, and concentrated his efforts to this end, backed by his sound engineering knowledge and innate sense of what would work.

It is easy to criticise from present-day standards, with the Second World War intervening, and the remarkable post-war developments of the past few years which have included entirely new power plant, better materials, new techniques, and a host of other items which, all combining together, have put into the hands of the aircraft designer of today many new tools, and given him many more opportunities.

The fact remains, however, that R.K.P.'s long family of designs were for the most part successful and built up an excellent and lucrative business for the Vickers Company both at home and abroad, between the two wars.

Most important of all, the cumulative effect over a long period of years of his sound engineering and great leadership, came to its zenith, most fortuitously, at a very critical time in the history of this country and enabled his firm to play a vital part in the gaining of air superiority in the Second World War.

PART IV

Having spoken of Rex Pierson's work, and given my personal impressions of him as a man and as a friend, in what practical way can we best do honour to him? I suggest by ensuring that enough men of his calibre and vision are drawn into British Aviation, to carry on and further his pioneering work.

What would he think of present-day aeronautical engineering in this country, and what would he most wish to see being encouraged?

I find these questions difficult to answer shortly and concisely, although we often talked of such matters. However, I believe that I know broadly some of the things he had in mind, and to which he intended to devote his attention.

I spent some time telling him of the new developments and research equipment we dug out during my several weeks' stay in Germany immediately after the war, and discussed at length a trip I took to the United States in 1946. I also have certain notes of his, written after the 1939-45 War, and his reports on future policy for the Advisory Committee, and from these I would advance the following:—

Being chiefly interested in large aeroplanes, he naturally expected considerable developments and changes in the big machines of the future for both civil and military types; but he did not subscribe to the large jumps being advocated at the time, and was in favour of a steady progression. In the light of current trends it would seem that he had a sound picture of the practical moves in this direction, for at least the first decade after the war. He was much concerned with the big increases in cost and size of aerodromes and the length of runways, and especially what would happen in this respect in the event of another war. He was obviously thinking a lot about this matter, and I believe had some ideas of how this problem might be tackled. I think he was interested in the flying boat for really big sizes.

He was worried about buried engines from an accessibility and fire risk point of view, and was sceptical about the elimination of petrol giving much relief from the risk of fire. He wanted as few large engines as possible, and did not like gearing two engines together, in fact he was apprehensive about the gearing problems on turbines altogether. He was very conscious of the value of the R.A.F. eradicating the teething troubles of a new design of engine in flight, apropos special civil engines, for which he was not enthusiastic.

He was interested in pressurisation, and we took a trip together to Yeovil in the early days of the new altitude chamber. He was keen on better engineering on what he called the operational services, and was unconvinced about electrics. We had several talks on power controls. He was thinking quite a lot about the offensive and defensive armament of bombers, and was adamant about pressing on with aids for safety for civil flying in bad weather.

Obviously I have not covered anything like the wide field of his thoughts, and his balanced mind had

undoubtedly grasped the necessity to install more aircraft research equipment as soon as possible after the war, although he was convinced that it was not necessary to go as far as some other countries, and that we must tackle this problem sensibly on a reasonable scale to meet our own particular needs. I feel he would be disappointed to see the slow progress on this matter in the intervening five years, since his death.

In one note written shortly before he died I see that he put staffing problems first, and although he had come up the hard way himself, and believed that there was still plenty of scope for the keen man along that same road, I feel he believed that we could do with more men in our future design teams with good academic background, as well as practical technical and shop experience, if they were carefully groomed for their work before being immersed in an executive job.

Also, that if the head of a future design team was to be efficient and able to call his soul his own, and have any home life at all, he must have a nucleus of top flight technicians in their own particular fields, backing him up, and sharing the load.

That, broadly speaking, we were now beginning to feel the lack of such people, might suffer seriously in the future if the gap were not filled, and that we had been fortunate in getting by so far with so few.

I expect a strong and loud disclaimer of this point of view. I shall be told that looking back over the years our outstanding technical men in the aeronautical world, as a rule, did not possess such a background; that today we lead the world in aircraft engineering, and that by and large the same conditions have always existed, and still apply today; that all is well, and that this plea for a wider scope on aeronautical technical education is unnecessary.

But I am quite unrepentent, and intend to hold firmly to this point. We lead the world today in aircraft because of the combined good qualities of a very few people, such as Rex Pierson, and because of their innate sound common sense, and wisdom to do the right thing at the right time. Wisdom is the greatest of these gifts, and is the vision with which knowledge is used, that intangible thing, a man's creative genius, which enables him to tackle each problem as it comes, in the right relation to the others, and from the correct standpoint. These qualities, which are a special British characteristic, provide the answer to the question why we are in this enviable position today in aviation.

This does not mean, however, that this very small band, upon whom so much has depended, would not have been even better if they could have been given a fuller background in their formative years and that, as each generation of leaders arises, this need will not grow greater.

Consider the difference in the nature of the tools in R.K.P.'s hands 25 years ago, compared with those of a chief designer today. For example, on one item alone, propulsion; at that time R.K.P. had the choice between three different makes of engine, which varied perhaps 15 per cent. in performance, but the combined power of the two selected engines for his bomber, at the operational height, certainly did not exceed 700 h.p. His counterpart today, if he uses two engines for his bomber, has available at least 20,000 h.p. under similar conditions, and if he employs not less than four engines, as he probably will, the figure will shortly be of the order of 60,000 h.p.

Throughout practically the whole gamut of aircraft design, the future chief designer and his team will be faced with similar changes, and still more complex problems, although there are certainly more aids to solve them.

You have heard how long it took Rex Pierson to design his first bomber, and this machine was in production in 15 months at a total cost of certainly not more than £100,000.

The Secretary of the American Navy has recently stated in public that it takes seven years and £25,000,000 to translate a new idea into a satisfactory production line of naval aircraft.

I do not suggest that we have yet got to this stage in Great Britain, and I hope that it may be some time before we do. I only quote these figures because I have no official yardstick to draw on at home, but they do bring out the complexity and seriousness of the design, making, testing, and tooling, of a modern aircraft and underline the necessity for having the best team possible in charge of it.

I have recently been living in France studying the aircraft designs and requirements of Continental Europe, in company with certain American technicians, and when I returned to England I took the opportunity of visiting the S.B.A.C. Farnborough Show, meeting a number of my old friends, and reading the eulogies of our national and technical press on the progress and superiority of British aircraft.

We have certainly made remarkable progress during the past six years, in spite of great difficulties. British aviation is to be congratulated and is in an enviable position, and practically all branches of industry are following the example of aeronautics in some new field or other.

Seldom has there been a greater challenge of the unknown in all branches of aviation, however. The next six years will produce greater advances, in my view, than the last, and inevitably this must lead to higher and higher accomplishment, a still greater increase in the tempo of aeronautical development and a heavier burden on the aircraft designer and his team.

This being so, I do not see around me any evidence which could entitle anyone to be smug or satisfied about our position. While I do not wish to under-estimate the importance of this lead that we hold in aeronautics, I would emphasise that it is a slender one and that nothing should be left undone to prevent it from dwindling, which it so easily can do, almost over-night. Our American friends are doing pretty well, and it seems as if they are bound to cash in fairly soon, with their mass frontal attack of elaborate research equipment backed by large staffs, which they invested in a few years ago; Soviet Russia's effort, although little is known about it from within, cannot be inconsiderable, as recent results from Korea have shown.

In taking this view, I am not criticising the remarkable efforts of our aircraft designers of today, and I would not attempt to outline here what the long-term development plan of the future should be. It is certain that we cannot afford in this country the very expensive research equipment laid down in other parts of the world for new aeronautical development, although as I have already indicated, there is some which I believe it is important for us to have as quickly as possible.

If we are going to maintain our lead, then one thing is certain: we have got to lay down longer range investments in the creation of the right brains, enough people with the best possible academic and practical background, having good personal qualities and leadership, possessing aggressive, restless minds, to head up, and strengthen the aircraft design teams of tomorrow.

Do not think that I am confusing the issue, and suggest exchanging the salt of the earth, the innate, sound common sense engineer who has accomplished so much in the past, for the impractical highbrow scientist. It is the realistic impartation of all three sides of a man's professional make-up, the blending of the fundamental sciences with the practical engineering and shop experience, together with the personal and leadership qualities, that will endow our future design leaders with the necessary power and wisdom to tackle the enormous jobs they have ahead of them. We must also provide them with sufficient similarly equipped lieutenants, although I do not consider that we require the very large staffs which are customary in the United States.

I speak from long practical experience, as I come from the same vintage and general background as R.K.P., and had to learn the hard way, and had to build up an engine design team of about the same order. It is a long and arduous task to constitute a good design team, and I was always searching for more good men, and when I had found one, there were always several jobs waiting for him.

It is surprising, also, how soon such a team can be dissipated, and I think it would be regrettable if we lost too many trained aeronautical technicians abroad at the present time, until our reserves are stronger. Of recent years I have had the good fortune to be able to stand back and appraise the constitution and make up of design teams both at home and abroad. It is most enlightening to see how individual teams are handled, how the whole tone is taken usually from one or two people, and how the success of the entire organisation depends on a few.

From what I have learnt I appreciate now, more than ever before—especially with the great increase in the technical complexity of modern aircraft—the urgent necessity, if we are to maintain our lead, to tackle this problem promptly, laying greater emphasis on quality rather than quantity; nevertheless I suggest that we want to build up a reasonable reserve, to meet the backlog at home and the calls of the Dominions abroad.

Incidentally, this might help our present production problems, as I have come back from the Continent rather appalled at the present position, and convinced that to keep a N.A.T.O. Air Force at anything like an efficient pitch in time of emergency, we must give a great deal more attention to the growing complexity and the standardisation of military aircraft.

Some of our present production difficulties, I suggest, can be laid at the door of the technical teams in the way their designs are broken down for production, and their manufacturing data passed over to the production factories.

What are we going to do about this matter; have I made a case and, if so, are people alive to it, and is it being tackled adequately and in time?

The answers to these questions, in my opinion, are that many serious-minded people in British aviation are alive to it, and want to tackle it. Certain others do not see the danger, and do not believe there is one, but if there is that it will solve itself. Generally speaking, with a few exceptions, I suggest that it is not being dealt with, mainly because the people most vitally interested are already working to their limit.

On principle, I do not like quoting outside authorities, but I feel I must do so in this case, in an endeavour to bring home to you the true position.

Last April the Advisory Council on Scientific Policy to the Ministry of Defence devoted the whole of their annual report to the Lord President of the Council on the needs of scientific and technological man power.

Most of you, I expect, read a short account of the report, and it can be bought for 6d. at Her Majesty's Stationery Office. It will suffice if I give the following comments from it:—

1. There is a pressing need to increase the number of all classes of mechanical engineers and scientists, adequately trained to the right level, and possessing high qualities of leadership and personality.
2. This shortage is not temporary but is likely to go on for years.
3. Engineering is not attracting as many boys of outstanding ability in England today as is necessary, and as could otherwise be attracted, were it not for certain counter-acting, out-of-date influences.
4. Many students with the possible ability to reach these standards leave school too early, and should remain until they are nearly 18.
5. There are not enough good teachers.
6. A further expansion of the facilities for higher engineering and scientific training is necessary.

This is a serious and important report produced by eminent people after many months of investigation. It includes not only the needs of qualified aircraft engineers, but comprises the requirements of all Britain for people trained in fundamental science and engineering, to the level of a university degree or equivalent qualification. The report was presented to Parliament by command of Her Majesty in May 1952, and apart from a debate in the House of Lords on it, in June last, I am not aware that anything has yet been done about it. Ministers are glad enough to talk about the export value of British aircraft in the years to come, but this cannot be of lasting value if they do not see that we have the wherewithal to maintain our lead with sufficient technically trained men, and adequate research equipment.

Information recently sent to me from America by my friend Mr. T. P. Wright, Vice-President for Research

of Cornell University, and an Honorary Fellow of the Society, sheds another light on this question.

This consists of the June 1952 Report of the Guggenheim School of Aeronautics of New York, and includes the latest report of the N.A.C.A. Design Committee set up to investigate the present capacity of qualified universities in the United States to train high grade aircraft personnel, and to give an expert opinion on the technical characteristics of equipment at these universities at the present time, and how much it is being used for training, together with some facts and figures on Cornell University Chair of Aeronautics. These make interesting reading, and broadly speaking the highlights gleaned from them are as follows:—

1. There is full appreciation of the urgent need for additional, adequately trained, aircraft engineers in America.
2. An estimation of the qualities required for a highly trained aircraft designer, with which I think we should broadly agree.
3. There is no need to worry about any downward trends for aircraft engineers in future.
4. The young man contemplating the technical side of aircraft engineering is in a happy position. Technical progress is rapid, and each time there is an advance engineering science opens the door to a new era of achievement.
5. Prospects and pay are good.
6. University facilities in U.S.A. are sufficient for all the aircraft students required, but are not being fully used.
7. Good teachers are scarce, and they are tending to go into the aircraft industry.
8. Independently from numbers, not enough of the best class of student is being attracted to aircraft engineering.

Apart from the fact that the British report deals broadly with engineers and scientists for senior posts in all branches of industry, and the American specifically for aeronautical engineers, it is remarkable how closely the broad patterns of the reports follow each other.

The Americans, who I should judge have made a realistic survey, say they just cannot get enough of the best brains to fill the aircraft technical pipe line, in spite of the fact that it is considered that the standards of academic training and equipment are good enough, and the pay and prospects when a man is fully qualified are excellent. One of the main reasons for this is stated to be that the glamour has gone out of aeronautics, which is now an accepted ordinary part of American life, and the best brains are seeking electronics and nuclear energy.

This is surprising, especially as it is understood that there is not in America any of the inferiority complex about engineering as a profession, that we still suffer from here.

I do not think we have ever had much of a glamorous period in aviation engineering in this country. I know things are much better now, but 40 years ago if your son went into engineering, it was one of those things you did not talk about. I had exactly the same experience as R.K.P., and had actually taken an examination to enter one of the accepted professions, when I managed to switch over to motor car engineering.

The British report says that it would not like to advocate any diminution at our universities in the arts or humanities, but I would not go as far as that.

I submit that first we must have enough of the very best brains of the country devoted to engineering and science, or else the time may not be far distant when there will not be much object in having a sufficiency of these older and deeply entrenched qualities of learning, however desirable they may be.

I noted with considerable interest that Lord Hives in his recent address to Nottingham University came out with a forthright statement that his firm has always been controlled by engineers. It has been an unfortunate thing, in my view, that engineers have not held their place on the administrative side of the British Aircraft Industry in the same way as they have in America and Germany. In my view the business man and the accountant still hold too much sway in this country, and Rolls-Royce are a shining example of the different approach to balanced management; but before British engineers can take their proper position in the top flights of industry two things have to be changed.

Firstly, the engineers must show by their balanced training and breadth of outlook that they are worthy to take the administrative posts, which the last generation, by and large, with notable exceptions, have not been because they left school too early, and had to work extremely hard in their younger, formative years; and secondly, we must shake off the shackles from the universities and other seats of learning, a problem which America and the Continent have not to grapple with, that it is not quite out of the top drawer to become an engineer.

I have made a point of trying to explain the present feeling in America on aircraft technicians because in the past we have been inclined to assume that there was not a problem there of this nature. Further, I think it is important to note that in America it is now being appreciated that high quality staff is essential.

Important things outside the control of the Aircraft Industry have to be done, but supposing our pipe line of first class technical people is adequately filled, how does the Industry stand then? I suggest that they have certain things to do also.

Most firms have schools at the apprentice level but these vary and there is still room for improvement, especially at the level of what is known on the Continent as the chartered design and factory engineer. Very few have a proper nursery, to borrow a cricket term, to bring on, finish off, and inculcate with the prestige and hallmark of the firm, the cream of their own people, and the basically well trained selected students who have come from the universities and other seats of learning, before taking up permanent posts within the company. Such a set up takes some time to build, although the staff entailed is small and the expense involved, apart from students' salaries, need not be regarded as serious. Some firms are not large enough

to tackle it in a broad way, but all can do something towards it, and the rest must come from suitable institutions, outside, and special courses.

It is not so long ago that there were no apprenticeship schools at all and youngsters had to fend for themselves and pick up what they could in the shops. It is equally important that there should not be a haphazard introduction into key posts in industry, of specially internally trained or qualified outside men without the final grooming period. It must be appreciated, as it is in countries like Switzerland, Sweden and Germany, that a fully qualified technological engineer is a profession requiring as long and faithful study as certain of the older and more entrenched professions, and that he must be paid a living wage while undergoing the finishing off process.

To sum up, I would suggest that:—

1. We must be convinced and sure in our minds that this is an urgent realistic matter, and not the vapourings of scaremongers who wish to ride some particular hobby horse or elevate technicians on to an unrealistic pinnacle.
2. We must appreciate that this is a long-term problem of profound importance to the life of the nation. We must go forward to the powers-that-be with a more concrete plan on this matter than has been attempted before, because at present it appears so complicated to them, particularly as we are divided in our opinions, and therefore senior people are apt to sheer off it.
3. We must influence and educate parents on the great value and permanent opportunities offered by the right aeronautical technical training.
4. We must convince the head masters of our public schools, and the well-informed hierarchy of this country, as well as the national press, the universities and other seats of learning, that a highly trained aeronautical engineer is a calling of the greatest importance, worthy of the best brains the country can produce, and just as vital to the community at large as the person embracing the accepted "liberal" education of the traditional professions.
5. We must see that the powers-that-be provide the facilities on an adequate but not grandiose scale, pay the teachers properly, and are alive to the urgent need of the present problem, and do something about it.

In conclusion I would emphasise that nothing I have said is intended to convey that I have the least doubt in my own mind, that the most important qualities of all, are those so clearly exemplified by R.K.P. of integrity, open mindedness and leadership, and that nothing can replace these.

I wish to thank those of the Vickers' staff, and others who have helped me in filling in some blanks in R.K.P.'s career. During the preparation of these notes I was sorely tempted to name more of his associates and helpers to amplify some anecdote in his work, but regretfully I have had to leave them out, as this address has already become too long. If I have done anything to bring home some of our urgent aircraft design needs for the future, I am sure I shall have satisfied my old friend and colleague, Rex Pierson.

N. E. ROWE (Chairman of the Branches Committee of the Society, *Fellow*): He congratulated the Weybridge Branch on the excellence of the attendance at the meeting and on having initiated what he was sure would be a most delightful practice—that of having a Main Lecture to commemorate the great ones of the aeronautical industry in this country. To have that lecture given at the Branches, where there would be many local associations, was basically a fine idea for which the credit would always be given to Weybridge.

Quite early in his career he had had the advantage of being posted to Weybridge as the resident officer of the Air Ministry from 1929 to 1934 and many of the illustrations Sir Roy had shown reminded him of the work that had gone on there and the keenness of Rex Pierson to get things moving. Rex Pierson drove everyone fairly hard, including himself, but he had got on well with him and they became great friends. During the 1939-45 War he had seen a good deal of him at the Ministry of Aircraft Production.

It was a fine thing to have had that account of his great achievements and at the end, the more serious note on general standards and how they were to educate engineers and leaders for the future. That was a big and unsolved problem.

His recollections of Rex Pierson were of an energetic leader, one who was quite sure of himself when he had thought things out. He went forward objectively and eagerly towards an ideal and inspired a splendid keenness in his own staff. He thought the lecture would be one of the means of continuing Rex Pierson's work.

W. E. W. PETTER (Managing Director, Folland Aircraft Ltd., *Fellow*): He remembered clearly the team work between Sir Roy Fedden and Rex Pierson on the Bristol engines which they at Westlands had tested both in machines of their own design and in others. This flight test work included many diesel and fuel injection engines which Sir Roy produced from time to time, to say nothing of the famous Mercury and Pegasus series.

He recalled, too, a very critical time in his own career towards the end of the war when those two gentlemen gave him much sound advice, on the lines indicated in the lecture, as to what an engineer should do to forward his career in spite of its inseparable difficulties. From what had transpired he thought that advice had not been entirely lost.

Rex Pierson was a good example of the true leader and one whom they would revere and remember. As far as his being in the middle of the road was concerned, looking on the post-war bomber of 1922, the clean lines of the little Venom fighter, which showed Rex Pierson's appreciation even in those days of the value of simplicity and compactness in combating the

ever-growing cost of military aircraft, and the Wellington bomber, he felt that they all showed surely that while Pierson never forgot his duty to fill his factory, he was looking ahead the whole time.

S. SCOTT HALL (Director - General, Technical Development (Air), Ministry of Supply, *Fellow*): He had had the privilege of being a student apprentice in the Weybridge works many years ago and of being associated with Rex Pierson and R. J. Knight, with whom he had had more practical dealings than with the Chief Designer.

Sir Roy Fedden had mentioned the question of production and had wondered how many people in this country were worried about it. He believed that quite a number of people worried about it, and for very good reasons. He felt it was a problem in which the Society should take an active interest. He believed that production was the biggest problem which British aviation had to face at the present time and everything Sir Roy had said about the problems of future design teams bore, he thought, with even greater emphasis on the question of future production teams.

H. KNOWLER (Director, Saunders-Roe Ltd., *Fellow*): In 1914 he answered an advertisement for an aircraft technician—"previous experience not essential." He was interviewed by Rex Pierson, then Chief Technician at Vickers, Crayford, who was only 23 at the time. The interview was somewhat informal, R.K.P. saying he had no experience of engaging staff, but, after a pleasant chat, that he thought "he would be O.K."

It was fun being an aircraft technician in those early days; everyone was very young and so was aviation. It was possible to learn everything known on the subject in a relatively short time. Mistakes were easily made and he thought that mistakes by others had given Rex Pierson his first chance. Although its was true that he was not officially appointed Chief Designer until 1917, his first machine was designed in 1915. It was a single-seat fighter—they were called scouts in those days—fitted with a 100 h.p. Gnome Monosoupape rotary engine, and was built at Joyce Green. Although originally unsuccessful it held considerable promise, and Rex Pierson was asked to re-design it.

Right from the beginning he was most weight-conscious and realised its importance in guaranteeing success. In the machine mentioned—called the E.S.1—the permissible weight rather than the probable weight was estimated, with the result that a very low target was set. This was 843 lb. and, to encourage keeping within the estimate, Rex Pierson had a bet with the Experimental Manager, Maxwell Muller, of one shilling for every pound he saved. The little machine was a great success, and had a high speed for those days, later becoming the F.B.19, or the Vickers "Bullet."

Rex Pierson was responsible for another machine before his appointment as Chief Designer, and later there were a number of other interesting types produced during the First World War before the advent of the Vimy.

The early flying boats which Rex Pierson designed were of particular interest to him. The Viking amphibian was an excellent machine for its era—in fact, it looked very similar to amphibians produced twenty years later.

Another flying boat, the Valentia, from his point of view, was perhaps the most interesting. The weight was just short of 20,000 lb.—a very big size in those far-off days. It was designed at Weybridge, but S. E. Saunders—later Saunders-Roe—were consulted on the hull construction and the machines were built and flown at Cowes.

Another very big flying boat, indicative of Rex Pierson's far-sightedness, was the Vigilant, which was intended to be powered by eight Rolls-Royce Condors, in coupled pairs, driving 21 ft. diameter propellers. It was in an advanced stage of preliminary design when it came under the Geddes axe. It was to weigh 110,000 lb.—an immense size to contemplate in 1919—and it was interesting to note that it took another ten years before a machine of this weight—the Dornier Do.X—was flown.

He had worked alongside Rex Pierson for 6½ years, and could speak personally of his innate kindliness and that somewhat rare quality—a capacity for "making allowances."

P. G. MASEFIELD (Vice-President of the Society, *Fellow*): This lecture set a precedent which he hoped would be widely followed. The lecture was notable as the prototype of a new form of presentation before the Society and equally for the way in which it had been delivered. Sir Roy had, indeed, really given them two lectures; one on Rex Pierson and the other, allied to it, on the need of trained engineers.

He regarded it as a great privilege to propose the vote of thanks to Sir Roy Fedden for the lecture on people rather than things. Looking round, the galaxy of talent which had come from the Industry all over England to hear Sir Roy was both a tribute to the subject of the lecture and to the lecturer himself.

It was, he thought, a great moment in the history of the Royal Aeronautical Society because for the first time, he believed, they were beginning to talk about people rather than ironmongery. Ironmongery in the form of aeroplanes came very closely into the picture because people were continually dealing with it, but he thought it a sign that they were growing up when they gathered together to remember those who had made personally such large contributions to aeronautical history. They were beginning to get a sense of perspective.

At the other societies and institutes one looked round the walls and saw that they commemorated the Watts and the Trevithicks and Stevensons and Brunells. Now they were beginning to get their great names—the Piersons, the Mitchells, the Chadwicks and the Barnwells—and he suggested that they should put the names of these and other pioneers in gold round the Council Room of their headquarters also. It was a happy thing that this new industry, and it was a new industry, should regard their admiration for Rex Pierson and the other great pioneers.

In his particular line of business on the operating side they came into contact with the genius of Rex Pierson every day. They were operating still almost his last aeroplane, the Viking, and they had cause to bless his name for it—on one or two occasions they said something else!—but they did appreciate it in the form in which it was still giving such magnificent service. The Viking which B.E.A. was operating today could perhaps be described as a Georgian version or maybe an Edwardian version—he was not sure which. But in its basis it was, and remained, a tribute to the far-sightedness of Rex Pierson.

They could learn a lot from the past and particularly from that point of view which had impressed him most, how to conduct a business with a team. That was a thing they all must continue to learn all the time. The aviation business changed, shapes changed, and even some of the materials changed. But the things which did not change were the things which Rex Pierson showed he knew so well and one of them was how to lead and inspire a team from the human point of view.

He thought a lot of them would remember what Sir Roy had talked about, and would ponder on the importance of integrity and of leadership. He had summed them up very well when he said they really amounted to wisdom and humanity. He could not help recalling the words of Stephen Spender which applied so well to Rex Pierson; he was one of those who " travelled a short while towards the sun and left the vivid air signed with his honour."

That was an expression of what Sir Roy had been telling them about. They had heard the story of a pioneer by a pioneer and he hoped that the new series of lectures recognising the human element would continue in the Society and teach them all something of a thing which did not change, and that was human nature.

He proposed a very hearty vote of thanks to Sir Roy Fedden who had given them such a feast of reminiscence. They were very grateful to him for bringing together so many pioneers.

J. LAURENCE PRITCHARD (*Hon. Fellow*), *contributed*: The lecture was divided into two parts which did not make a satisfactory whole. The result was, and a deservedly natural result, that all the comments were confined to the first half of the lecture dealing with the personality and achievements of R. K. Pierson. Nevertheless, the second half, dealing with the education of aircraft technical personnel, was of more importance. It was one upon which much could be said and it was to be hoped that there would be a considerable discussion upon the controversial points raised and some hard hitting on the subject generally (at one time the discussions of the Society were lively and worth while, in contrast to those of the present aeronautical budgerigars who cooed to one another and the lecturer).

How right the lecturer was to lay the emphasis on quality rather than quantity! How loudly called out the business man for *more* men and how rarely did he attend a technical meeting of the Society to find out their quality, that quality upon which the very success of the business depended!

The late Howard Flanders, in a lecture to the Institution of the Aeronautical Engineers in 1924, said, discussing the early days of aviation, " 1912 opened with the bugbear of commercialism beginning to destroy the feeling of good fellowship."

Sir Roy Fedden, in this lecture, said, " Today, in my view, the business man and the accountant still hold too much sway in this country."

But what did Sir Roy Fedden mean by " balanced training and breadth of outlook "? Who did the balancing and who measured the breadth? What was the curriculum? To be frank this kind of phrase savoured of " leaving no stone unturned " beloved of the politician.

Sir Roy wanted engineers to take their proper position in industry and questioned their ability to do so for their lack of balanced training and outlook. Was that not the fault of the methods, which were increasing in the fields of educational training, of specialised training instead of the teaching of fundamental principles? The more one specialised the less breadth of outlook one had. Too many scientists as well as engineers in aviation were degenerating into technical shoptalkers who only listened to the one customer who provided them with the ways and means to carry on the conversation.

The properly trained civil or mechanical engineer could deal with most engineering problems in aircraft engineering, but it would not be true to say that the aircraft engineer could return the compliment. What were wanted were all-round engineers.

Measurement of Gust Loads in Aircraft

by

J. TAYLOR

(Structures Department, Royal Aircraft Establishment)

1. Introduction

Fatigue of aircraft parts due to small but numerous vibrations has been known about for some time, but in 1944-5 cases of structural fatigue were found which were thought to have been caused by loads greater, but less frequent, than the usual vibration loads. Such loads could be ground loads due to taxi-ing, take-off and landing or they could be air loads caused by gusts and manœuvres.

A general study of the fatigue properties of typical structures was made in the laboratory and it became apparent that the loads likely to do the most damage were those occurring about a million times in the life of the aircraft. A further problem arose immediately. What was the magnitude of these loads?

Much information was available on the size of loads which occurred about once in the life of an aircraft. Such loads have been determined indirectly by relating the number of accidents with the design strength requirements. This method is accurate, although there is naturally more information on ground loads, because structural failures on the ground do not normally involve loss of life, whereas structural failures in the air are practically always fatal. In recent years the information on air loads has been supplemented by flight measurements with the N.A.C.A. *V-g* recorder. In effect, this instrument plots aircraft acceleration against air speed; the resultant is an envelope curve, which shows the highest acceleration occurring at any particular air speed but obliterates the lower accelerations. An extrapolation of the records will give a reasonable estimate of the magnitude of the loads which occur a thousand, or possibly ten thousand, times in the life of an aircraft but beyond that the predictions become unreliable.

Occurrences of 10^8 and above are of a continuous vibration character and were reasonably well known from vibration measurements taken in short experimental flights. Thus the problem still remaining to be solved was the measurement of the loads occurring from about ten thousand to ten million times in the life of an aircraft. There are two main causes of such loads—ground taxi-ing and gusts. Flight manœuvres, touchdown, and take-off are regarded as secondary, since they do not occur frequently. The equipment described has been used satisfactorily for the measurement of both ground taxi-ing and gust loads but, for convenience of presentation, only the measurement of gusts is described.

Received August 1952. Based on a talk given to the Polytechnic Institute of Brooklyn, 2nd May 1952.

2. Relationship between Gust Loads, Strain and Acceleration

Unlike manœuvre loads, which are reasonably steady for a few seconds, gust loads are transitory. The load builds up to a maximum and then begins to reduce almost immediately, the complete duration of the load being of the order of one second.

This time of load application is so short that the strain and acceleration at any point in the structure is influenced by the wing inertia and flexibility. This dynamic load effect produces perturbations up to about 20 per cent. in the wing strains and is important in the study of individual gusts. The only way of studying individual gusts is by measuring the strain and acceleration at a number of stations. For any one particular gust of unknown structure there is the additional complication that the load is probably asymmetrical and the strain and acceleration at one point cannot be used to predict the strain and acceleration at any other.

Figure 1 shows diagrammatically the accelerations and strains at a number of points on a wing, on passing through a gust with a sharp gradient. The strain and acceleration are both in two parts. There is an overall strain and an overall acceleration, corresponding to a rigid body motion, together with secondary strains and accelerations of cyclical character at about the natural frequency of the wing. The amplitude of these secondary

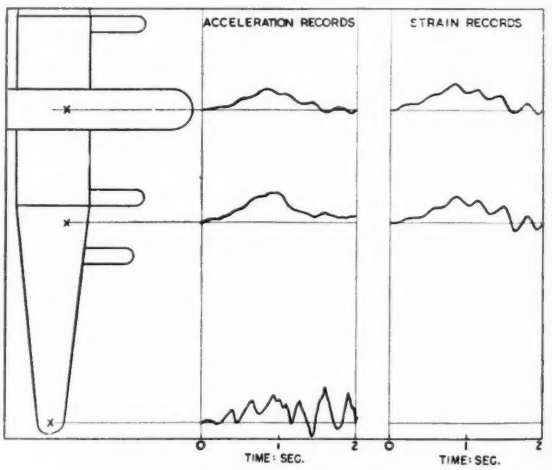


FIGURE 1. Acceleration and strain in a gust.
(Extracted from work by Mrs. A. Burns)

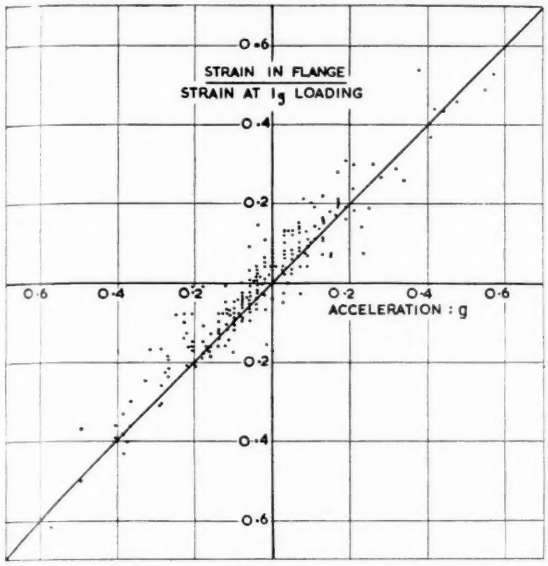


FIGURE 2. Comparison of strain and acceleration.
(*Extracted from work by J. B. Lambe*)

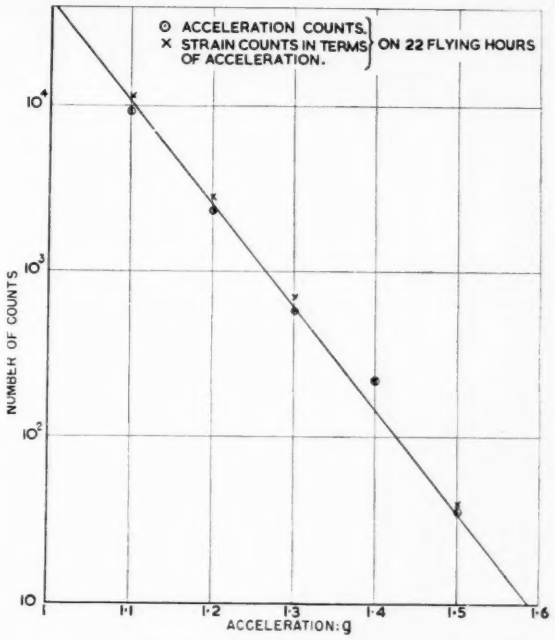


FIGURE 3. Acceleration and strain counts on same aircraft.

strains is about 20 per cent. of the main strain at each point along the whole wing. The amplitude of the secondary accelerations reduces from a maximum of 120 per cent. at the tip to zero at the nodal line and then increases to a maximum of 15 per cent. at the centre line.

The best position for a single accelerometer to indicate average strains in the structure is near the aircraft c.g. for, apart from including dynamic effects of the right order of magnitude, it is practically unaffected by any angular acceleration of the aircraft as a whole. A typical correlation for individual gusts of the acceleration of the c.g. and the strain in the centre section is given in Fig. 2. There is a scatter of about $\pm 0{\cdot}2g$ but the average is the same whether accelerations or strains are measured. This information is also compared in Fig. 3 by giving the numbers of strain counts and numbers of acceleration counts at different levels. In this diagram the individual character of any particular gust has been lost and it is shown that the number and magnitude of gust loads on a wing structure can be deduced from the measurement of accelerations at a point near the c.g. of the aircraft. Attention will now be concentrated on the study of the acceleration at this one point.

3. Discussion on Information Required from Acceleration Records

Superimposed on the accelerations and strains due to gust loads are high frequency vibration accelerations arising from the power plant. Fig. 4(*a*) shows the total acceleration and the total strain at a position near the aircraft c.g. The strain is hardly affected by the vibration, but the acceleration has a high frequency component which obscures the other components.

It is evident that for a proper study of gust loads this high frequency acceleration, originating at the power plant, must be rejected from the record. This is done in Fig. 4(*b*), the correlation between gust strains and accelerations being apparent.

This example is an obvious case of unwanted information. In fact it would be extremely laborious to separate the high frequency acceleration from a record once it had been recorded. The true acceleration at the station is that given in Fig. 4(*a*), but the one required for the study of gusts is that in Fig. 4(*b*).

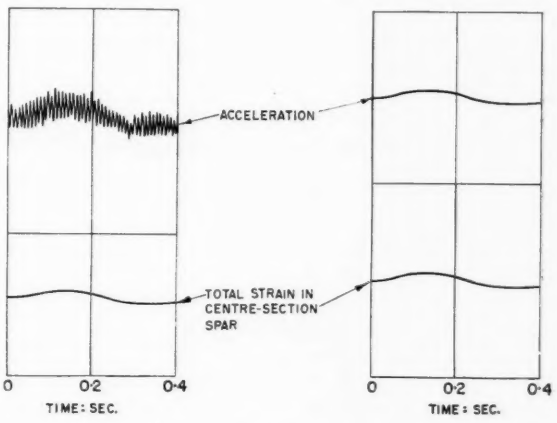


FIGURE 4.

(*a*) Combined gust and vibration acceleration and strain.

(*b*) Gust acceleration and strain with vibration acceleration removed.

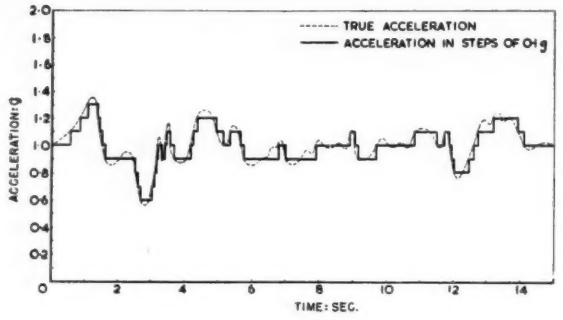


FIGURE 5. C.G. acceleration-time record.

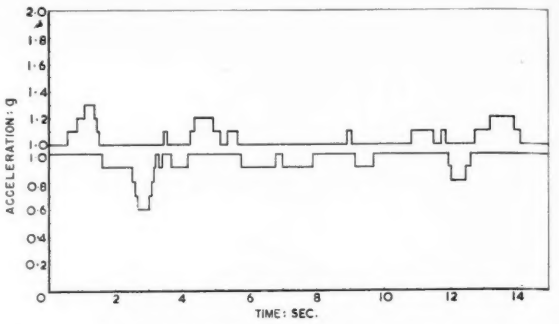


FIGURE 6. C.G. acceleration-time record of Fig. 5 in steps of 0·1g. Accelerations above and below 1g separate.

It is preferable that this rejection of high frequency accelerations be done by the accelerometer itself. Fig. 4(*a*) is a record of acceleration for two-fifths of a second and the analysis time to reduce it to the form of Fig. 4(*b*), if it had to be done manually instead of by the instrument, would be several hours, that is more than 10,000 times the time taken to obtain the record. This is only the first stage in the reduction of the analysing time. A record of the same form as Fig. 4(*b*) is given by the dotted curve of Fig. 5, but of $\frac{1}{4}$-minute duration. It must now be decided what are the salient features of this record, having due regard to the fact that it represents only $\frac{1}{4}$-minute flying, whereas records from tens of thousands of hours flying time are required.

The first decision to be taken, is the magnitude of fluctuation which can be disregarded. Having done this and decided, say, that 0·1*g* is the minimum step to be considered, the curve can be simplified to the form given by the full lines of Fig. 5. To obtain this curve in steps the accelerometer must be such that, once it is recording at any particular level it continues to do so until the acceleration changes to an adjacent level 0·1*g* above or 0·1*g* below.

So far little has been lost from the original curve and, because of its continuous nature, it could be reconstructed reasonably accurately from the record in step form. It is unlikely that this reconstruction would be required for more than a half a minute's flying per hundred hours and the time required for the reconstruction is small compared with the time saved in the other 99·999 per cent. of the record. The next step is to identify the datum and this is done in Fig. 6 by replacing the single curve by two curves, one to record acceleration above the datum and the other to record below. Finally the record must be read. For fatigue, it is sufficient to know the value of successive maxima and minima accelerations. These can be read off by counting the number of steps from the datum lines.

As time between successive maxima and minima, as opposed to total time required to produce a particular pattern, is unimportant it is possible to reduce the size of the records by stopping the recorder whenever the curves are on the datum lines. As the starting cannot be instantaneous the first bump of any series is distorted near the datum. A typical record of a few gusts with nine consecutive minutes completely calm is shown in Fig. 7, the upper line being a time marker. In this particular record the recorder was stopped for 99 per cent. of the time. Reading from left to right the successive maxima and minima are 1·0*g*, 0·9*g*, 1·1*g*, 1·0*g*, 1·1*g*, 0·7*g*, 1·1*g*. These ranges of acceleration between adjacent maxima and minima accelerations are tabulated and grouped under the maxima and minima accelerations identifying them. This is correlated with the number of times that the various thresholds of accelerations are crossed. In this connection a threshold

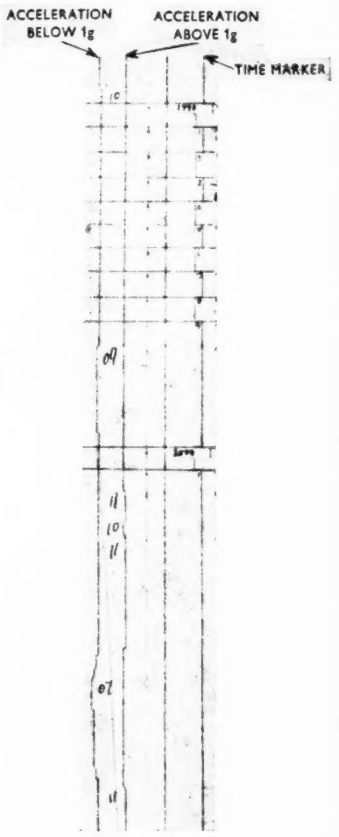


FIGURE 7. Typical c.g. acceleration-record in steps of 0·1g.

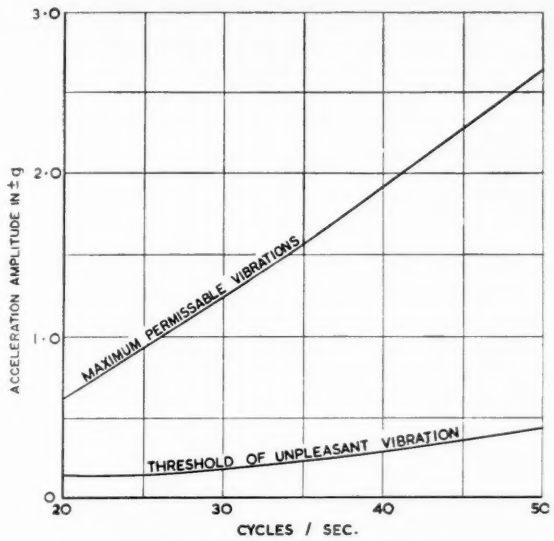


FIGURE 8. Accelerations due to vibration.

is a band of acceleration of 0·1g width. This correlation between ranges of acceleration and thresholds crossed is obtained on a limited sample of flying and it is then assumed to hold for extensive flying in which only the number of times the thresholds of acceleration are crossed, are recorded.

4. The Design of an Accelerometer

The properties of the accelerometer and the recording device have to be selected to give the information required from the acceleration records. The rejection of the vibration acceleration from the combined gust and vibration accelerations has to be done by the accelerometer itself; the particular method of recording must be done by the recording unit and a suitable adaptor to the accelerometer.

The permissible vibrations in aircraft structures are laid down in Air Publication 970. Fig. 8 gives the vibration levels in terms of acceleration instead of in terms of the usual deflection. The maximum permissible vibration at 40 cycles/sec. is about $\pm 2g$ and a large attenuation is necessary if the record from such a vibration is to become small compared with the gust accelerations down to 0·1g. On a continuous record it is possible to retain an appreciable amount of the vibration acceleration and to reject it finally by inspection of the curve, but it is clearly preferable to reject as much as possible before the record is made. This adjustment by inspection gives discretion and mental effort to the analyst. The objective in making an analysing accelerometer is to reduce the mental effort to a minimum. It must, however, reduce the discretion at the same time and so the requirements for the accelerometer must be more stringent. In particular, the rejection of high frequency acceleration must be to a high accuracy.

The gust loads in an aircraft vary relatively slowly. In designing an accelerometer, this means loads of low frequency components. Thus an accelerometer for measuring gust loads has two main requirements; it should record faithfully the low frequency accelerations due to gusts, and reject as completely as possible the high frequency accelerations due to vibration. The main decision concerns the frequency at which the change over should occur and then the change over must be as rapid as possible.

A study of structural strains due to gust loads shows that the predominant frequency is less than about 2 cycles/sec. and that the main perturbation is at the natural frequency of the wing. It is considered that the perturbations at about $1\frac{1}{2}$ times the wing frequency are small and that above $2\frac{1}{2}$ times the wing frequency they may be completely disregarded. It is proposed therefore that the change over should be made as near as possible to $2\frac{1}{2}$ times the wing frequency. Thus for a wing of natural frequency 4 cycles/sec. the best accelerometer to use is one with a change over at 10 cycles/sec. Accelerometers are made in several ranges and the most suitable for a particular aircraft is chosen, preference being given to the accelerometer with a range higher than the ideal.

There are two ways in which an accelerometer can record erroneously a combination of sinusoidal motions. The first is by an error in amplitude, which is given as the amplitude response ratio of measured to applied amplitude. The second is by distortion, which is given by the differences in time lag at different frequencies. The distortion error is quite as important as the amplitude error. It is not the absolute value of time lag that matters, for obviously no distortion would occur if every acceleration were recorded precisely one hour later. The time lag at zero frequency is taken as the standard, and change in time lag is the relevant parameter. The units chosen for recording change in time lag are degrees of phase at the recorded frequency.

A simple accelerometer consisting of a mass and spring with velocity damping is given in Fig. 9. By suitable choice of damping and natural frequency of the

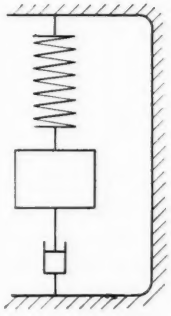


FIGURE 9. Simple accelerometer.

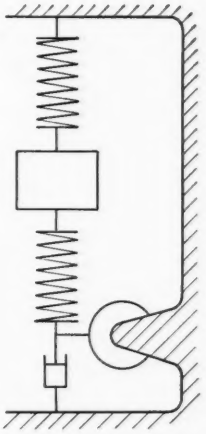


FIGURE 10. Compound accelerometer.

mass on its spring, any required accuracy at low frequency can be achieved. The high frequency response is hardly affected by damping and it is practically fixed once the natural frequency of the mass on its spring is chosen. There would be no advantage in compromising the low frequency response by a change in damping to improve the behaviour at high frequency. The simple accelerometer is quite inadequate for measuring gust acceleration, where there are appreciable high frequency accelerations to be rejected. This is particularly true for a counting accelerometer.

A satisfactory compound accelerometer can be made by adding a secondary spring and a rotary inertia to the simple accelerometer and by putting the damping on the rotary inertia (Fig. 10). As in the simple accelerometer, the damping has to be chosen to suit the low frequency response and has little effect on the high frequency behaviour. There are, however, two additional parameters in the rate of the secondary spring and the magnitude of the rotary inertia.

By examining mathematically a series of secondary springs and a series of rotary inertias, the best compromise is found. On this basis it is considered that a compound accelerometer should have the following properties:—

(*i*) The rotary inertia should have an inertia equivalent to a mass on the end of the secondary spring of 0·35 times the main mass.

(*ii*) The secondary spring rate should be 1·25 times the rate of the main spring.

(*iii*) The damping should be such that the rate of change of amplitude response is zero at zero frequency.

Figure 11(*a*) gives the distortion errors. The change in time lag of the compound and the simple accelerometers are compared. Up to 6 cycles/sec. the behaviour of both types is good. Between 6 and 10 cycles/sec. they each have adequate performance but the simple accelerometer is the better. Above 10 cycles/sec. the accelerations have to be rejected and so distortion errors have no meaning and are omitted.

Figure 11(*b*) gives the amplitude response ratio of the compound and the simple accelerometers. Up to 6 cycles/sec. the behaviour is good and is much the same for each accelerometer. Between 6 and 10 cycles/sec. they each have adequate performance but the compound accelerometer is the better. Above 10 cycles/sec. the compound accelerometer rapidly becomes superior and is completely satisfactory for the attenuation of vibration accelerations.

The effect of vibration is shown quantitatively in Fig. 11(*c*). Even for the maximum permissible vibration in an aircraft structure the compound accelerometer will record less than 0·01*g* for all frequencies above 30 cycles/sec., whereas the simple accelerometer records more than ten times this amount.

A practical compound accelerometer is shown diagrammatically in Fig. 12. The main spring and mass are in the form of a cantilever spring with a mass on the end. The secondary spring consists of two spiral springs with a steel band to form an endless belt over two pulleys. The springs are pre-tensioned to allow

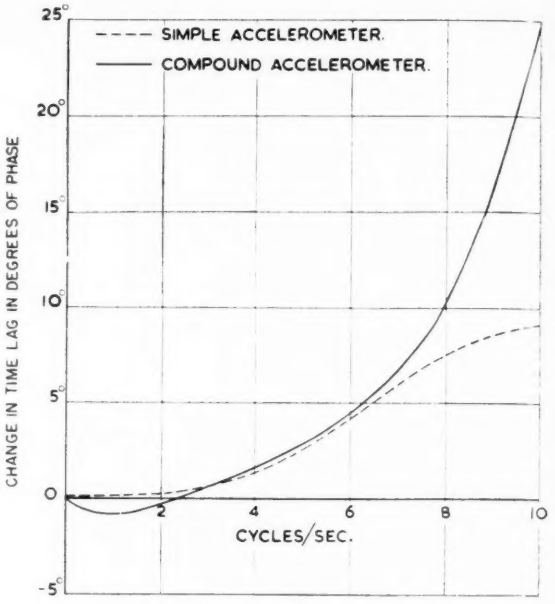


FIGURE 11(*a*). Change in time lag.

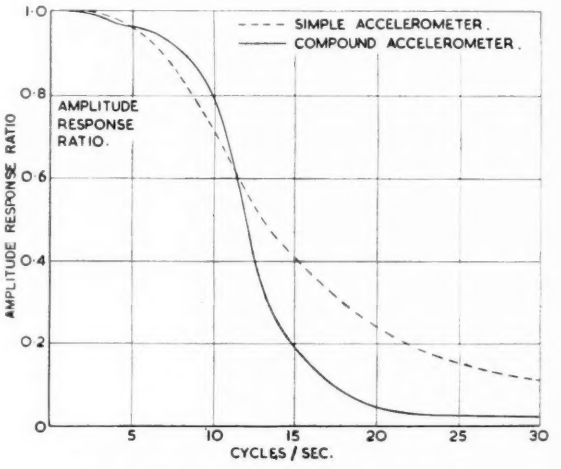


FIGURE 11(*b*). Amplitude response ratio.

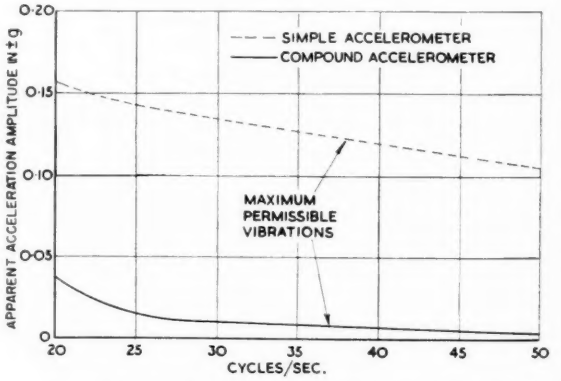


FIGURE 11(*c*). Apparent acceleration under vibration.

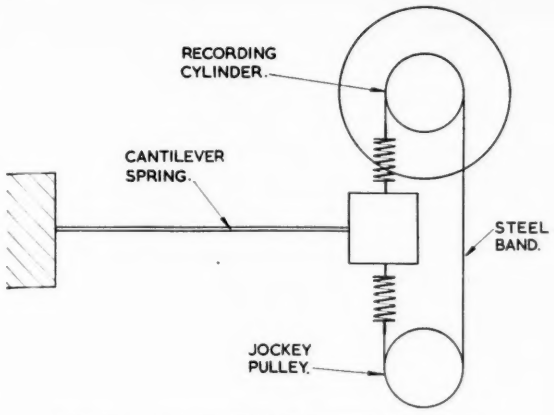


FIGURE 12. Diagrammatic representation of actual accelerometer.

the belt to transmit compressive as well as tensile loads. The steel band is firmly fixed to the recording cylinder, which has a disc added to make up the full rotary inertia.

Eddy current damping is used to give angular velocity damping to the rotary inertia. Sufficient damping is achieved by connecting the recording cylinder through a step-up gear of 9 to 1 to a hollow aluminium cylinder rotating in the field of a permanent magnet between the poles and a central iron core. This form of damping is linear with velocity to within one per cent. as shown in Fig. 13. Such a unit was re-tested after a year's operation in an aircraft and found to have retained within one per cent. the same magnitude and linearity with velocity.

Another feature of the gearing is that the aluminium cylinder rotates in the direction opposite to the remainder of the rotary inertia. Thus, by having a sufficiently strong permanent magnet it was arranged that these two

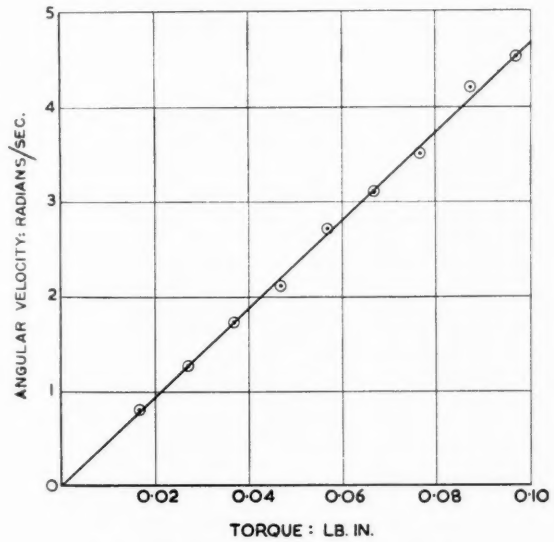


FIGURE 13. Characteristics of damper unit.

inertias were approximately equal and the unit was unaffected by angular acceleration.

5. Recording of Acceleration Particularly by Counting

The practical details of the design of the accelerometer must depend to some extent on the type of recording head to be used. The particular one being described is a Counting Accelerometer, and the back view is shown in Fig. 14(*a*). The cantilever spring is 10 in. long and the brass mass on the end is 2 lb. so that the applied accelerations will develop sufficient force to operate mechanical counters without appreciable change to the readings. The secondary spring of two spiral springs and an endless belt, together with the jockey pulley, are visible, but the recording cylinder is hidden by the permanent magnet of the damper unit. The constancy of the damping is particularly important in the counting accelerometer as the instrument is completely unattended in operation.

The pointer arm is on the same shaft as the upper cylinder and is visible in Fig. 14(*b*). As the continuous tape is attached to the upper cylinder, the cylinder and the pointer are restricted to a rotation of 180°. To save space in fitting the counters, both ends of the pointer are used to operate counters at alternate thresholds.

Two operations are required to make a count. First the pointer must pass the ratchet on the end of the counter and subsequently, when the pointer returns, as it must, towards the datum, it catches the tooth of the ratchet and moves it on to make a count. There are two special features in this operation. In the first part of the motion there is only the slight friction of the light pointer on the ratchet and the acceleration level at which the pointer actually passes the tooth is well defined. In the second part of the motion a finite acceleration change is required to make the count. This is important for otherwise counts could be recorded by the superposition on a steady acceleration of minute fluctuations, which do negligible structural damage. The change of acceleration required to make a count is approximately $0{\cdot}1g$ with well-defined edges away from the level flight datum.

It is essential that there shall be no miscounts due to the inertia of the counters. First, a count must not be missed due to the flexible pointer moving rapidly and being unable to overcome the inertia of the counter. Secondly, the counter once set in motion must not make two counts due to its own inertia. Both these conditions are avoided by interposing a flexible spring between the very light ratchet wheel and the counter. Thus, very rapid changes of acceleration are possible but the rate at which successive counts on individual counters can be made is limited. The particular instrument will not miscount for a virtually instantaneous change of acceleration of $2g$ and any one counter will count successive impulses at up to 10 per second. Overload tests have shown that breakdown is not imminent at either of these conditions.

The accelerometer with the front face in position is shown in Fig. 14(*c*). Each threshold of acceleration is

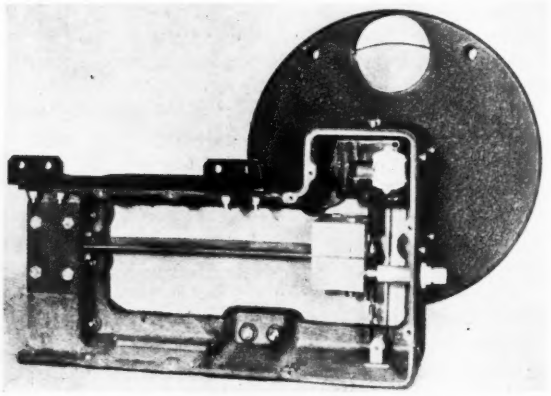


FIGURE 14. Counting accelerometer. (*a*) Back view.

shown, but successive levels are on opposite sides of the face because both ends of the pointer are used to operate counters. Also, for convenience in marking the face, only the edges of the threshold away from the level flight 1*g* datum are marked. Thus, for example, the threshold 1·3*g* to 1·4*g* is marked 1·4*g* and the threshold 0·7*g* to 0·8*g* is marked 0·7*g*. The full range of the instrument is in steps of 0·1*g* from 0 to 2·0*g* and in steps of 0·2*g* from −1·0*g* to 0 and from 2·0*g* to 3·0*g*. The total weight is 12 lb. and the instrument is 13 in. high by 18 in. by 5½ in.

An electrical version of the counting accelerometer was made for the early testing of the accelerometer. In the form in which it was made it weighed 50 lb. and was far too heavy for routine use, although it was useful as a research accelerometer, since it was easily adapted to give an acceleration record in 0·1*g* steps. Complete records were taken for 17,500 miles flying on three types of aircraft to determine the general pattern of the acceleration ranges and to correlate it to the threshold of acceleration crossed. The remainder of the gust investigation on these types can be made by the mechanical counting accelerometer and it may be well over a million miles.

6. Counting Accelerometer in Service

From fatigue considerations on a particular aircraft it is only necessary to count the various thresholds of acceleration crossed. For application to other aircraft or even to the same type of aircraft operating under different conditions it is necessary to know further the operating speeds and heights. In this way a Gust Spectrum can be built up and can then be used at the aircraft design stage.

This Gust Spectrum is being measured on selected aircraft by adding to the Simple Counting Accelerometer an automatic observer which photographs, automatically every ten minutes, the acceleration counters, and the readings for speed, height and time. This Combined Counting Accelerometer, shown in Fig. 15, has double the weight and volume of the Simple Counting Accelerometer and requires much more attention. The films have to be changed every 25 flying hours and the records analysed.

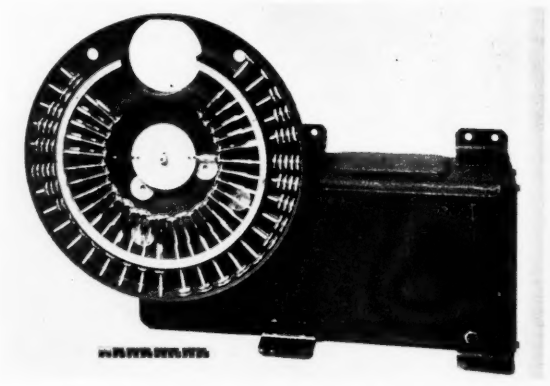


FIGURE 14(*b*). Front view with front face removed.

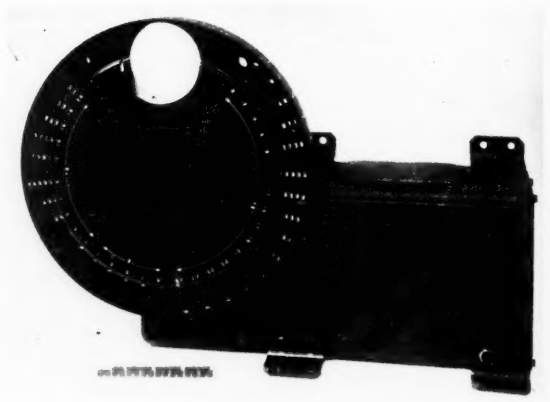


FIGURE 14(*c*). Front view.

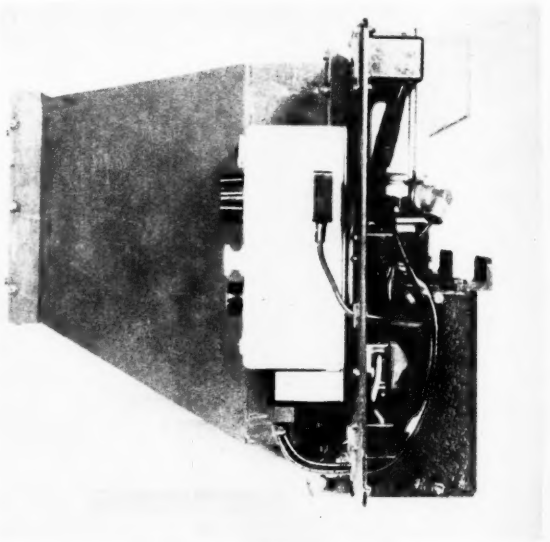


FIGURE 15. Combined counting accelerometer.

TABLE I

COUNTING ACCELEROMETER RECORDS ON VIKING V.W.217

Speed in tens of knots	Height in thous. of feet.	Recorded time in 1 minute intervals	Time after Take off (P) or Landing (N) in tens of mins.	* No. of times thresholds of acceleration crossed in ten minute intervals																		
				0.1g to 0.2g	0.2g to 0.3g	0.3g to 0.4g	0.4g to 0.5g	0.5g to 0.6g	0.6g to 0.7g	0.7g to 0.8g	0.8g to 0.9g	0.9g to 1.0g	1.0g to 1.1g	1.1g to 1.2g	1.2g to 1.3g	1.3g to 1.4g	1.4g to 1.5g	1.5g to 1.6g	1.6g to 1.7g	1.7g to 1.8g	1.8g to 1.9g
00	00	0010	01	000	0	0	0	0	0	00	00	000	000	001	000	00	00	0	0	0	0	0
00	00	0020	02	000	0	0	0	0	0	00	00	000	053	066	000	00	80	0	0	0	0	0
00	00	0030	03	000	0	0	0	0	0	00	01	023	131	133	023	01	00	0	0	0	0	0
00	00	0040	00P	000	0	0	0	0	0	01	07	040	153	156	037	09	01	0	0	0	0	0
10	02	0040	00P	000	0	0	0	0	0	00	03	009	030	041	011	03	00	0	0	0	0	0
14	08	0050	01	000	0	0	0	0	0	00	00	005	035	054	016	02	00	0	0	0	0	0
15	11	0060	02	000	0	0	0	0	0	00	00	000	013	018	003	00	00	0	0	0	0	0
15	11	0070	03	000	0	0	0	0	0	00	00	000	004	007	000	00	00	0	0	0	0	0
14	11	0080	04	000	0	0	0	0	0	00	03	016	046	056	024	06	02	0	0	0	0	0
15	08	0090	05	000	0	0	0	0	0	01	02	014	066	075	031	09	03	2	1	0	0	0
16	04	0100	06	000	0	0	0	0	0	01	06	016	054	076	019	09	02	0	0	0	0	0
16	03	0110	07	000	0	0	0	0	0	01	03	021	086	134	024	05	00	0	0	0	0	0
15	03	0120	08	000	0	0	0	0	0	00	00	005	042	070	016	00	00	0	0	0	0	0
14	03	0130	09	000	0	0	0	0	0	00	00	002	015	048	041	17	02	0	0	0	0	0
14	03	0140	10	000	0	0	0	0	0	00	00	000	007	090	020	04	01	0	0	0	0	0
				000	0	0	0	0	1	01	03	007	051	1025	265	65	11	2	1	0	0	0

*One count is made when the threshold is crossed once in each direction.

The records are read and the counts for each ten minutes punched on Hollerith cards. These are printed and a typical chronological record is given in Table I. These are subsequently sorted by machine into height and speed bands, and a typical record is given in Table II. The use of sorting machines is essential for work of this kind but plans must be made carefully before the work reaches large proportions. The system in use was developed gradually during the whole of 1951 while the number of records to be analysed was relatively small and small changes to the card arrangement could be tolerated. The system is now stabilised and will probably be used for several million flying miles without change.

7. Results

Before examining the counts of thresholds crossed, a study will be made of the pattern of acceleration met. The results to be shown were obtained on a Viking, but they are substantially the same on the other aircraft. Fig. 16 shows a three-dimensional model representing the ranges of acceleration. The co-ordinates of the columns are the maxima and minima accelerations which identify a particular range of acceleration, and the height of the column is the number of times that range occurred. As the counts have to be made finite and definite steps of acceleration, the columns have a finite and definite cross section.

TABLE II

VIKING V.W.217

SPEED IN TENS OF KNOTS	HT IN 1000 OF FT.			TIME IN 10's OF MIN	Nº OF THRESHOLDS OF ACCELERATION CROSSED																	
					0·1g TO 0·2g	0·2g TO 0·3g	0·3g TO 0·4g	0·4g TO 0·5g	0·5g TO 0·6g	0·6g TO 0·7g	0·7g TO 0·8g	0·8g TO 0·9g	0·9g TO 1·0g	1·0g TO 1·1g	1·1g TO 1·2g	1·2g TO 1·3g	1·3g TO 1·4g	1·4g TO 1·5g	1·5g TO 1·6g	1·6g TO 1·7g	1·7g TO 1·8g	1·8g TO 1·9g
10	000			0010	00	00	00	00	00	000	001	0002	0022	0015	0006	002	000	00	00	0000	00	00
13	000			0010	00	00	00	00	00	000	001	0010	0052	0039	0014	002	001	00	00	0000	00	00
14	000			0010	00	00	00	00	00	001	009	0030	0115	0148	0028	007	001	00	00	0000	00	00
15	000			0110	00	00	00	00	02	006	019	0117	0607	0719	0172	051	017	06	03	0200	00	00
16	000			0140	00	00	00	00	00	001	016	0109	0445	0519	0119	029	003	01	00	0000	00	00
17	000			0040	00	00	00	00	00	001	002	0011	0078	0135	0011	001	000	00	00	0000	00	00
18	000			0040	00	00	00	00	00	002	014	0062	0291	0493	0159	065	025	11	02	0100	00	00
19	000			0010	00	00	00	00	00	000	001	0004	0029	0025	0002	000	000	00	00	0000	00	00
				0370	00	00	00	00	02	011	063	0345	1639	2093	0511	157	047	18	05	0300	00	00
12	050			0010	00	00	00	00	00	001	001	0003	0016	0035	0015	002	000	00	00	0000	00	00
13	050			0010	00	00	00	00	00	000	000	0000	0010	0009	0000	000	000	00	00	0000	00	00
14	050			0200	00	00	00	00	01	003	019	0107	0541	0623	0162	045	009	01	01	0000	00	00
15	050			0410	00	00	00	00	00	002	014	0086	0519	0688	0145	035	009	03	01	0100	00	00
16	050			0310	00	00	00	00	01	007	040	0168	0906	1287	0225	064	008	03	00	0000	00	00
17	050			0080	00	00	00	00	00	000	003	0018	0128	0217	0040	006	000	00	00	0000	00	00
18	050			0070	00	00	00	00	00	000	003	0024	0120	0168	0029	003	000	00	00	0000	00	00
				1090	00	00	00	02	04	014	080	0406	2240	3027	0616	155	026	07	02	0100	00	00

There are two pronounced humps, one at a minimum of 0·8*g* to 0·9*g* and one at a maximum of 1·1*g* to 1·2*g*. This hump at 0·8*g* to 0·9*g* minimum means that on average the maximum accelerations of all magnitudes have adjacent minimum accelerations between 0·8*g* and 0·9*g*. This phenomenon may also be stated as meaning that, on average, accelerations due to gusts build up to a maximum from a little below 1*g* and return to about the same level. The same argument applies for the hump at 1·1*g* to 1·2*g*.

This is most convenient for the analysis of the thresholds crossed because it means that there is little error in assuming that, when one threshold of, say, 1·3*g* to 1·4*g* is crossed, all other thresholds between 1*g* and 1·3*g* are also crossed at about the same time. The only time this does not occur is for the few occurrences to the left of the plane at 1*g* minimum and to the right of the plane at 1*g* maximum.

Figure 16 also shows that up and down gusts of the same magnitude are not normally adjacent to each other, otherwise the hump would be at 45° to the axes; while this is frequently assumed in fatigue calculations, it is definitely conservative. Table III gives the thresholds crossed in the flying examined in Fig. 16 and they are compared with the actual number of acceleration peaks exceeding the particular levels. The differences are so small that they could not be shown graphically.

TABLE III

COMPARISON OF THRESHOLD COUNTS AND PEAKS

Thresholds in intervals of g	*Number of times threshold crossed*	*True number of peaks beyond the threshold*
0·4 to 0·5	5	5
0·5 to 0·6	13	13
0·6 to 0·7	40	40
0·7 to 0·8	209	210
0·8 to 0·9	1,129	1,137
0·9 to 1·0	6,489	6,549
1·0 to 1·1	7,305	7,480
1·1 to 1·2	1,453	1,478
1·2 to 1·3	323	327
1·3 to 1·4	66	67
1·4 to 1·5	18	18
1·5 to 1·6	7	7
1·6 to 1·7	1	1

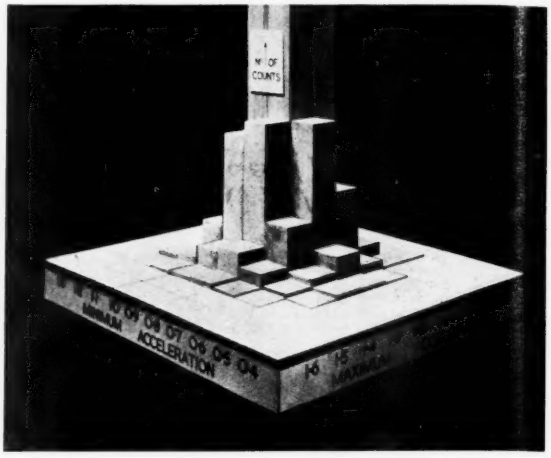


FIGURE 16. Ranges of acceleration.

A further special investigation was made with a Viking to find the effect of speed. The aircraft was flown for four-minute periods alternately at 120 and 180 knots equivalent air speed (E.A.S.) with a one-minute interval between each, to change speed. Ten flights were made, each of ten complete cycles of this procedure. In this way there were 100 four-minute records of flying at 120 knots interposed with 100 four-minute records of flying at 180 knots. Fig. 17 shows that the miles per gust of any magnitude are the same at the two speeds.

Having decided that threshold counts give a good representation of peaks and that miles per gust is a good parameter for a particular aircraft flying at

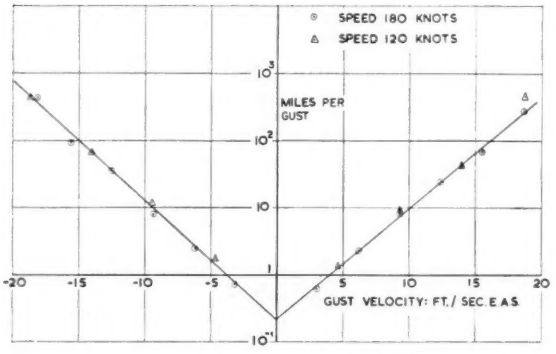


FIGURE 17. Gusts met by Viking at two speeds.

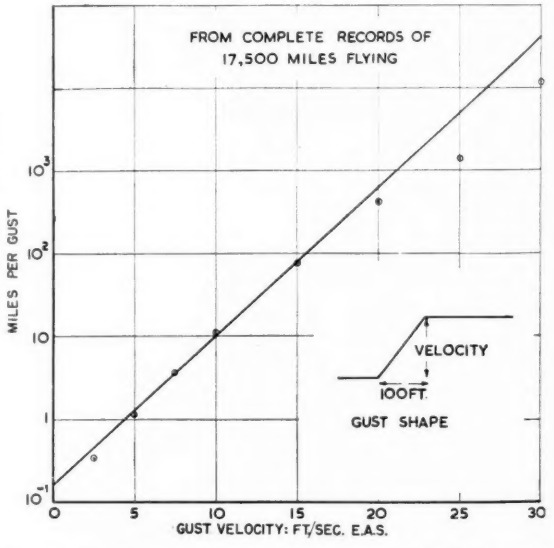


FIGURE 18. Average gust spectrum for aircraft flying up to 12,000 ft. in terms of miles per gust of given magnitude or greater.

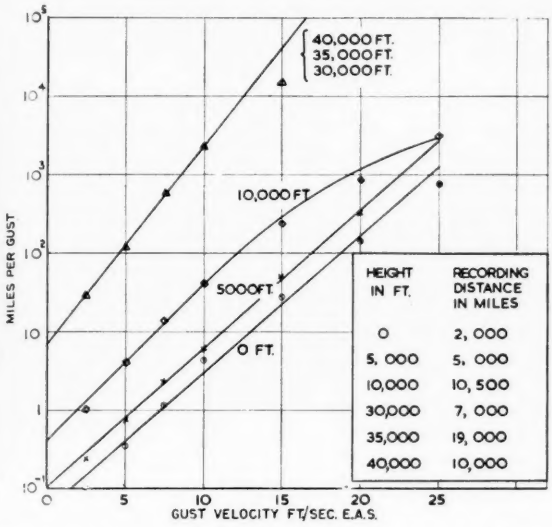


FIGURE 19. Gust spectrum at different height bands in terms of miles per gust of given magnitude or greater.

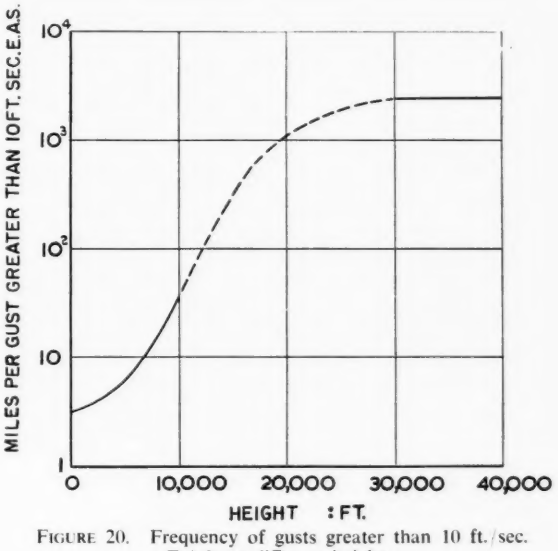


FIGURE 20. Frequency of gusts greater than 10 ft./sec. E.A.S. at different heights.

different speeds, it is proposed to give the counts on the different aircraft in terms of miles per gust. Fig. 18 shows the average miles per gust of low-flying aircraft. The circles are the experimental records of the whole of 17,500 miles flying.

The 17,500 miles flying will now be separated into height bands of zero to 2,500 ft. and bands of 5,000 ft. width with means of 5,000 and 10,000 ft. A further record of 35,000 miles flying in a Comet at 30,000, 35,000 and 40,000 ft. bands has been added to form a composite picture (Fig. 19). The positive and negative gusts at a given magnitude occur in practically equal numbers and the sum of them is given. The miles flown in the different height bands are:—Ground level, 2,000; 5,000 ft., 5,000; 10,000 ft., 10,000; 30,000 ft., 7,000; 35,000 ft., 19,000; 40,000 ft., 10,000. There is substantial agreement between the records from the different aircraft at each height. A good impression of the relative frequency at the different heights can be obtained by comparing the numbers of gust speeds exceeding 10 ft./sec.

The cross plot at a gust velocity of 10 ft./sec. is given in Fig. 20. Although a curve is drawn between 10,000 ft. and 30,000 ft. there is not much information available. There are records of 10,000 miles of flying in the Comet, which agree with the general trend from 10,000 to 30,000 ft., but they have not been included as they were taken almost invariably in the climb or descent and the Comet has an appreciable change in height in ten minutes, the interval chosen for recording.

8. Gust Spectrum and Fatigue

To find the effect of gusts on fatigue the conservative estimate that each up gust is associated with a down gust of equal magnitude is assumed. Also, for illustration, it will be assumed that the damage due to gusts at one magnitude is cumulative to that at any other magnitude and that for each magnitude the damage is in the direct ratio of the actual number occurring to the number required to produce failure.

With this basic assumption, the damage is calculated for a hypothetical aircraft with the load-endurance curve shown in Fig. 21, and given for convenience in terms of gust velocities at its actual cruising speed. The same figure shows the number of gusts that will be expected in five and ten million miles flying. As the aircraft flies farther the curve of gusts met is uniformly to the right and eventually it will touch the endurance curve. This is the size of gust which does the most damage in fatigue. The damage to be expected per million miles is given in Fig. 22. The area under the curve* is the total damage, the ordinates being

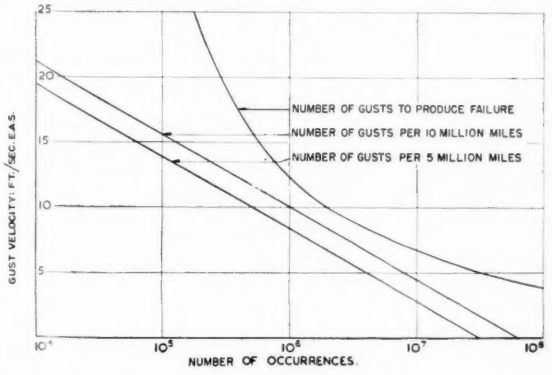

NUMBER OF GUSTS TO PRODUCE FAILURE
NUMBER OF GUSTS PER 10 MILLION MILES
NUMBER OF GUSTS PER 5 MILLION MILES
GUST VELOCITY: FT./SEC. E.A.S.
NUMBER OF OCCURRENCES.

FIGURE 21. Load-endurance of structure and gust spectrum.

*Dr. Chilver demonstrated in an unpublished work that cumulative damage could be expressed in mathematical form as a continuous curve.

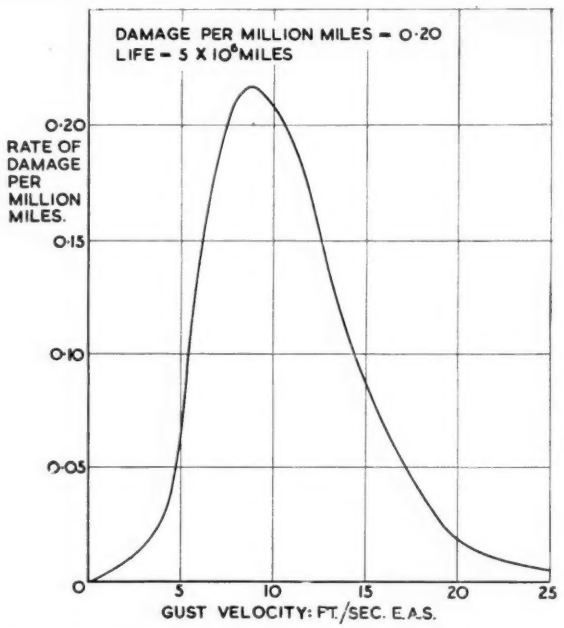


FIGURE 22. Comparison of fatigue damage and gust velocity.

proportional to the rate of damage for the particular size of gust. It can be seen that only a little damage is caused by gusts less than 4 ft./sec. or greater than 20 ft./sec. and that maximum damage occurs at 9 ft./sec.

For the particular case it would be expected that the aircraft would meet sufficient gusts to break it up in five million miles. To decide how far to allow such aircraft to fly, a safety factor would be required.

9. Future Development

The process of collecting data for use in the design of aircraft is a continuous one. This is as true for the assessment of small gusts, with special reference to fatigue, as for any other operational research. In the first place complete records of acceleration and strain were taken for a small amount of flying. The total recording time was only a few hours, but the analysing time was thousands of hours.

The next stage was the recording of one acceleration record in steps, and the next stage occurred immediately by omitting the blanks from the records. This work was used to determine the feasibility of using a counting accelerometer. It has been used for over 100 hours recording time and will be continued at the rate of about twenty hours for each aircraft type under investigation.

The counting accelerometer is in use in both the compound and simple forms and makes counts at a large number of acceleration levels.

Dr. Walker in his lecture "Fatigue of Aircraft Structures" (*Journal R.Ae.S.*, August 1949) suggested that an instrument might be carried on all transport aircraft as a fatigue indicator. When more information has been collected on counting accelerometers it may be possible to fit a very simple accelerometer to every aircraft and let it count at one level only, preferably near the most damaging level; when it has counted various predetermined numbers, replacement of various parts of the structure will be made. This has obvious advantages compared with a flying-hour replacement scheme, as it would benefit those aircraft that had been fortunate enough not to have suffered much fatigue damage, either owing to climatic conditions or to the pilot flying slowly in turbulent air.

Temperature Control of Jet-Engined Aircraft

by

E. W. STILL, Ph.D., B.Sc., A.C.G.I., F.R.Ae.S., A.M.I.Mech.E.

(Research and Development Manager, Teddington Controls Ltd.)

Introduction

The rapid development of the jet engine has been responsible for a complete change of outlook in air transport. The purpose of this paper is to illustrate some of the problems and to indicate ways in which they have been solved. The subjects discussed are those of temperature control of

(*i*) Pressure cabins of aircraft

(*ii*) Engine intakes (for de-icing) and

(*iii*) Aircraft wing surfaces (for de-icing).

The normal control of engine jet pipe temperature has not been included because, until recently, it has been fully covered by the engine companies.

Jet pipe temperature control is a specialised application involving the correction of fuel flow for variations of air flow which may be due to changes in either compressor or turbine characteristics at altitude, or even the incorrect sampling of jet pipe temperature at altitude. The methods of temperature control discussed in this paper are often applicable also to engine jet pipe temperature control.

The paper starts with a statement of the problem, then discusses cabin temperature control systems, control methods, anti-icing, de-icing and ice indicators, and concludes with an attempt to look ahead and outline the fundamental problems to be overcome in the next few years.

1. Statement of the Problem

The change from the piston to the jet engine has meant that, because of the large quantities of air available, many aircraft services are now operated from the air supply off the jet engine compressor. It is one purpose of this paper to study the control of such compressed air.

Initially there was considerable opposition from engine designers to the tapping of the compressor for this purpose, but the case was so strong that in England it has now become accepted as standard practice. In the United States the auxiliary power plant has some adherents, but this method would seem to add considerably to the weight of the overall system, so that the claimed advantages must be analysed carefully.

Only axial type jet engines have been studied, with thrusts ranging from 8,000 to 12,000 lb. and compression ratios from 6 to 10:1.

Compressor air flows and air outlet temperatures have been assumed from typical non-dimensional curves (Fig. 1).

It will be noted that the air temperature rise through the compressor, even for a 6:1 compression ratio, is quite high, but it must be remembered that compressed air must still have sufficient pressure at aircraft ceiling altitudes to supply the needs of the crew in the cabin at minimum cruise engine r.p.m.

These curves, when translated into absolute pressures at high altitude, as shown in Fig. 2, indicate that it is not possible to use lower compressor ratio tappings at high altitudes. If this had been possible it could have meant considerable simplification of the temperature control systems which, at present, have to operate at extremes of both air pressure and temperature.

The next problem is to consider the requirements of the pilot and the climatic conditions in which he may be flying.

Figure 3 indicates the absolute pressure and temperature existing up to 70,000 ft. The lowest cabin pressures recommended at present are the equivalent of 8,000 ft. altitude for civil aircraft and 25,000 ft. for

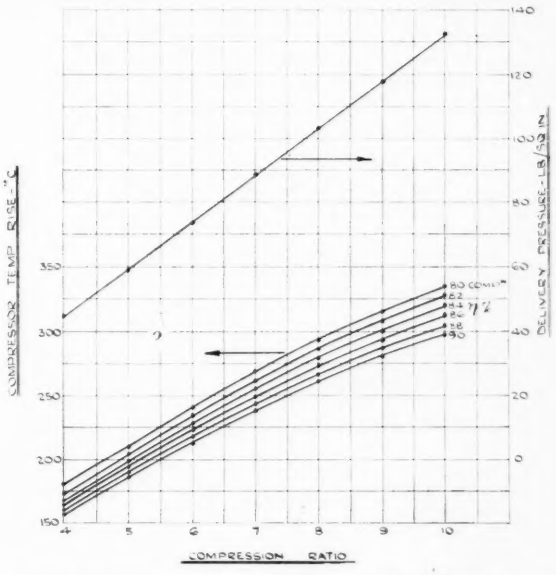


FIGURE 1. Compressor temperature rise and delivery pressure.

A Section Lecture given on 30th October 1952

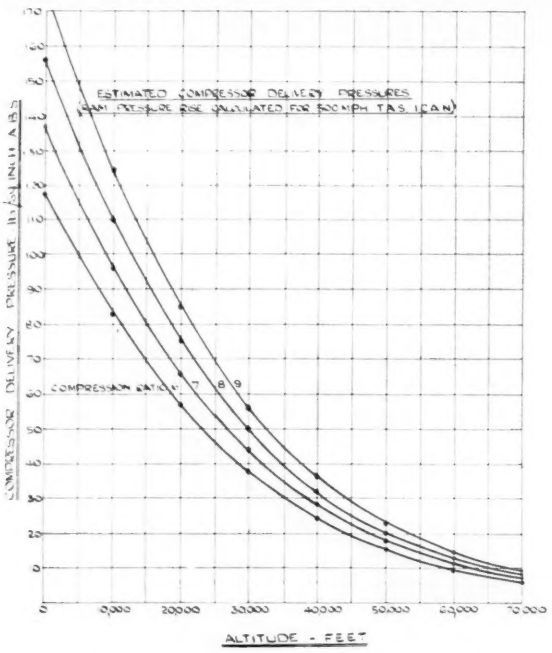

ESTIMATED COMPRESSOR DELIVERY PRESSURES
(RAM PRESSURE RISE CALCULATED FOR 500 MPH TAS ICAN)
COMPRESSOR DELIVERY PRESSURE lb/sq in ABS
COMPRESSOR RATIO 7 8 9
ALTITUDE - FEET

FIGURE 2. Compressor delivery pressure at altitude.

bomber and fighter aircraft. These pressures mean that the engine r.p.m. should never be such as to allow the engine delivery pressures to fall below these figures. Usually the minimum r.p.m. increases with altitude and hence, caters for this situation.

Typical figures for the engines and types of aircraft are shown in Table I, which illustrates the wide range of temperatures and pressures involved.

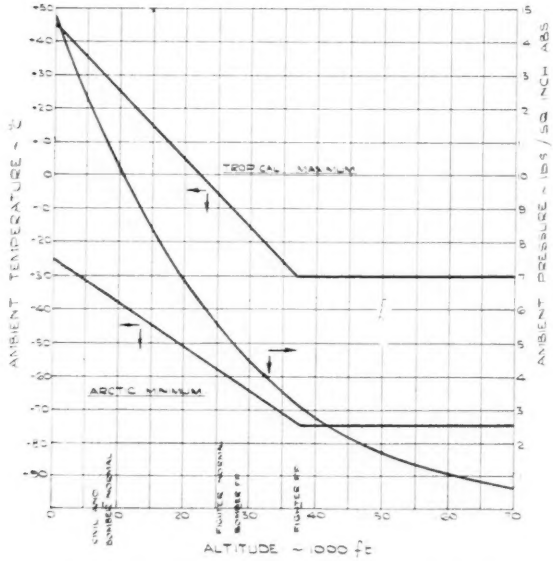


FIGURE 3. Temperature and pressure altitude data.

It is the control of the supply of heat for these widely varying conditions which is the special subject of this paper.

Another aspect which merits consideration is the effect of bleeding air off the compressor for aircraft services. Fig. 4 shows the engine thrust reduction resulting from the bleeding of varying amounts of air from the compressor. While the amount required for military aircraft cabins is not large, even at high altitude, careful thought must be given to the quantities required for engine and wing de-icing.

Normally the high percentage bleed shown in the "let down" case is not important as it occurs only at high altitude. Passing down through cloud the loss of thrust is less and is only of short duration. The baulked landing, power on, is one case when maximum power is required and some loss of thrust is inevitable. The other is when the aircraft is climbing through ice. This is the worst case and may represent 30 per cent. loss of thrust at the top of the icing altitude (30,000-35,000 ft.). In no case should range be affected, as jet-engined aircraft should normally fly above icing conditions.

Because of the loss of engine thrust which results from the big demands in the de-icing systems some designers have turned to:—

(*i*) Methods of electrically heating engine intakes and wing surfaces and

(*ii*) Using ram air suitably heated by way of a heat exchanger off an exhaust gas tapping.

The first idea is particularly applicable to civil aircraft, where large reserves of electrical energy may be available from the pantry.

The method using ram air has something to recommend it, since it is well known that axial compressors

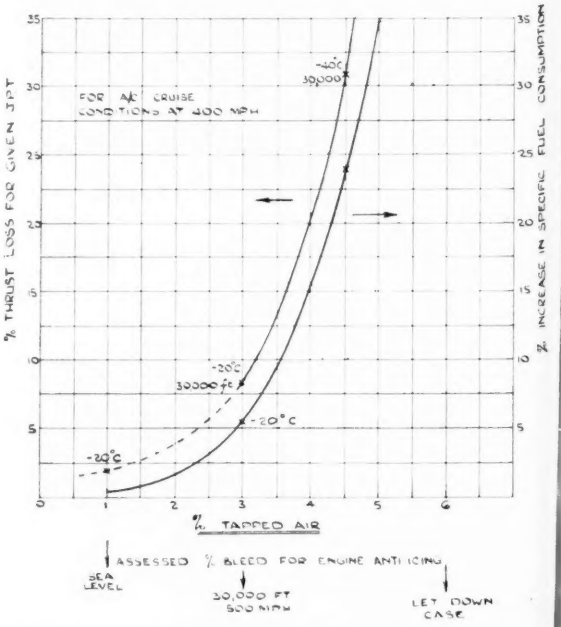


FIGURE 4. Loss of thrust due to bleeding air from compressor

are sensitive to surge troubles if bled of much air at indefinite moments. Theoretically, it is considered that the use of gas tapped between turbine stages has much to recommend it, but this gas cannot be used directly in the aircraft wing as it is too hot and may contain corrosive acids and condensation products. Thus it becomes necessary to transfer this heat to rammed air, entailing extra weight and complication of controls. Heat exchangers to cool the gas from 800°C. are regarded by many designers as an unwarranted risk.

These difficulties have resulted in the attempt to use electrical methods of heating, but in general this has been limited to relatively small units because of the available electrical energy.

The method of bleeding hot gas direct from the engine involves considerable problems of design because of the high temperatures.

In reviewing the engine and cabin conditions mentioned before, the first point to notice is that the use of the jet engine compressor has deleted the need for any auxiliary heater for cabin, wing or engine heating. It is now a case of cooling the compressed air over quite a wide range of temperature. Table I shows that the maximum cooling is required at sea level on a tropical day. A primary cooler is used for this purpose, but Fig. 6 shows that even a unit having a thermal ratio of 0·9 still fails to give sufficient cooling.

This has resulted in the development of the cold air unit, which in its latest form is a turbine driving a fan, and in so doing, reducing its air temperature and acting as a refrigerator. The fan is often used to provide an air flow for the primary cooler and hence to give some ground cooling. Fig. 5 shows a photograph of a typical compressor turbine Cold Air Unit (C.A.U.).

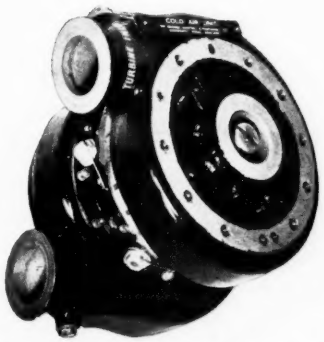


FIGURE 5. Cold Air Unit.

Courtesy of Sir George Godfrey and Partners Ltd.

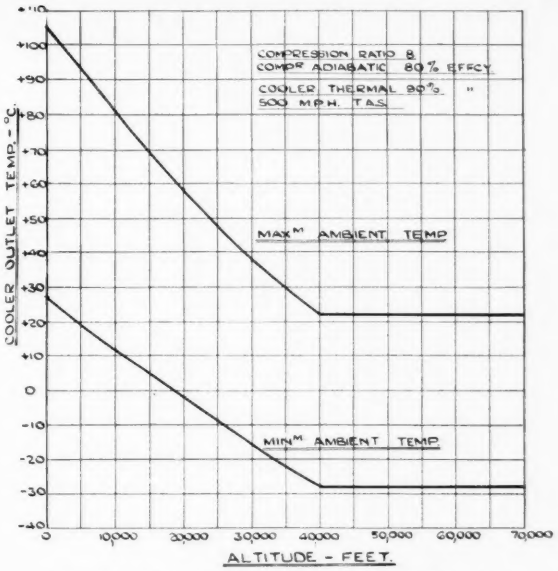


FIGURE 6. Cooler outlet temperature versus altitude.

Referring again to Table I, it will be noted that at high altitude all the heat is required to keep the cabin warm and hence, the primary cooler must be by-passed. At intermediate conditions the cold air unit can be by-passed.

Besides these conditions there are other minor limitations, the first of which is that the refrigeration must not reduce the duct air temperature to freezing point or the ducts will frost up and the humidifier become blocked with ice.

If air temperatures are too hot then the hot air may damage the ducts which are often made of plastic to keep the weight to a minimum. Similarly, excessively hot air entering the leading edge of the aircraft wing may reduce its strength factor to a dangerous figure. Other cases have been known where the air was too hot and created discomfort when impinging on passengers' feet.

Before explaining the details of the control system governing these factors, it will be well to examine the general layout of the major units and their details.

TABLE I

COMPRESSOR TEMPERATURES AND PRESSURES FOR VARIOUS ALTITUDE CONDITIONS

Condition	6 *to* 1 *compression ratio*						8 *to* 1 *compression ratio*						9 *to* 1 *compression ratio*					
	100% *r.p.m.*		80% *r.p.m.*		60% *r.p.m.*		100% *r.p.m.*		80% *r.p.m.*		60% *r.p.m.*		100% *r.p.m.*		80% *r.p.m.*		60% *r.p.m.*	
	Temp. °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A.	*Temp.* °C	*Press.* P.S.I.A
Sea level A.P.970 Tropics 45°C	309	90	219	55	136	305	420	153	312	94	215	52	447	172	336	105	234	58
Sub-Arctic −25°C	232	118	153	72	82	40	278	158	192	96	114	54	301	178	211	108	131	60
20,000 ft. I.C.A.N.	233	56	154	35	83	19	279	76	193	47	115	26	301	85	211	53	131	29
40,000 ft. I.C.A.N.	197	27	121	17	52	9	215	32	136	20	64	10·6	235	36	154	23	79	12·0
60,000 ft. I.C.A.N.	197	10	121	6·5	52	3·5	215	12·3	136	8·0	64	4·3	235	14	154	9·0	79	4·8
70,000 ft. I.C.A.N.	197	6·95	121	4·3	52	2·3	215	8·2	136	5·1	64	2·7	235	9·3	154	5·7	79	3·1

Air speed = 500 m.p.h. Assumed compressor efficiency = 80%

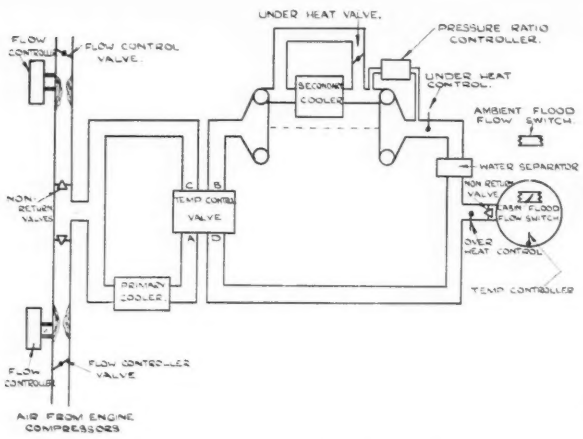


FIGURE 7(*a*). Diagram of typical cabin control system.

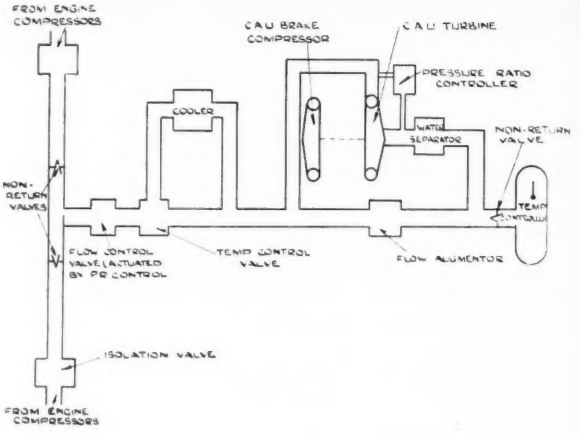


FIGURE 7(*b*). Diagram of typical cabin control system.

2. Cabin Temperature Control Systems

Figures 7 (*a*), (*b*), (*c*) and (*d*) show in line diagrams the disposition of the main components of the cabin temperature control layout.

Almost every aircraft has its own special features and it is in this field that it is considered that some standardisation of outlook should be made and where simplification is essential. For example, why have more than one valve to control? (Fig. 7(*d*)).

Full temperature control can only be obtained by a gradual change from full heat to full cold, which means that both the primary cooler and C.A.U. must be capable of being by-passed. However, if the diagrams in Fig. 7 were the limit of the requirements then the systems could be simple indeed. In actual fact there are a number of practical limitations which tend to complicate the control, although some of these features should be designed out of the system.

The first is that on a tropical take-off, the cabin may call for such cooling as to try to reduce the duct temperature below freezing point. This results in the frosting up of the ducts downstream of the C.A.U. and the freezing up of the humidifier. Two methods are being used for solving this trouble. The cabin really calls for a certain B.Th.U. load of cooling. Normally cabin air flow is controlled to a constant figure, proportional to the number of the crew in the aircraft.

If the maximum reduction of temperature has been achieved from the pre-cooler and C.A.U. (without frosting), then more cooling can only be obtained by increasing the cabin air flow.

The alternative is to extend the period of time necessary to achieve the required cabin temperature by the fitting of a stabiliser, or interrupter, in the actuator circuit of the hot air valve.

Both these methods are being used to prevent duct frosting.

In the first case the normal air flow is increased in proportion to the amount of cooling required after the C.A.U. has already brought the air temperature down to its minimum figure of about $+3^{\circ}$C.

This is done by an air flow rate controller, as shown in Fig. 9, which virtually gives the normal flow controller a progressively false datum, depending on the cabin demand.

3. Components

3.1. PRIMARY COOLER

Today these are air-to-air coolers, usually built of light alloy sheet or small tube nests, brazed together.

FIGURE 8. Temperature control valve.

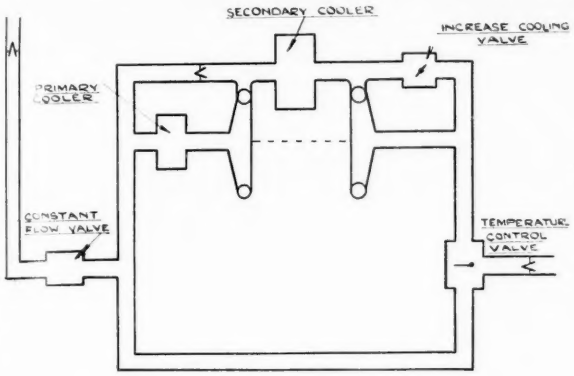


FIGURE 7(*c*). Diagram of typical cabin control system.

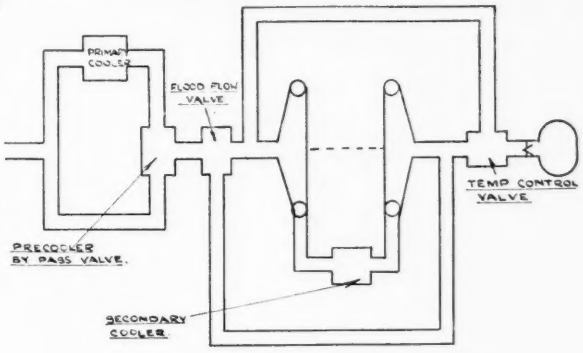


FIGURE 7(*d*). Diagram of typical cabin control system.

They have a thermal efficiency of approximately 90 per cent. That is to say, within certain air cooling flows they will reduce the hot air temperatures to 90 per cent. of the initial temperature difference between the two air streams. Typical curves and data are shown in Fig. 6. Applying suitable sizes to the aircraft under consideration immediately shows that a cooler alone is quite incapable of providing the full cooling required.

A point commonly not appreciated is that at a Mach number of one, a 50° compressive temperature rise is created at the cooler intake, this increasing to 200°C. at a Mach number of two.

Such figures show that for the high-speed fighter of the future, primary cooling alone will not avail, as even at a Mach number of one at sea level in the tropics, the cooling air entering the cooler will be over 90°C.

On the other hand, it must also be appreciated that this is the temperature at inlet to the engine compressor and hence it will still be possible to reduce the compressor temperature to near the tropical compressibility temperature, which would be in the region of 100°C. This, in itself, provides the reason for the refrigeration supplied by the Cold Air Unit.

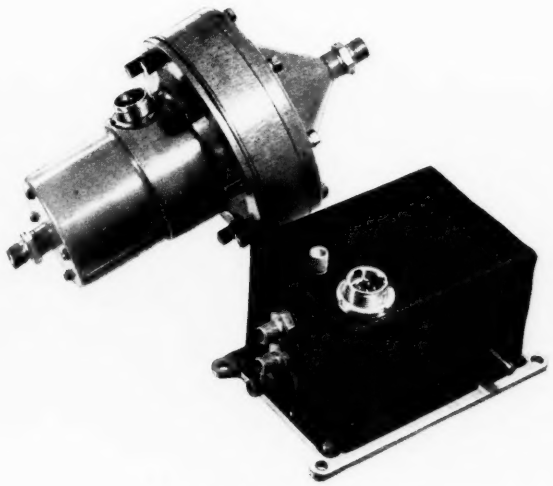


FIGURE 9. Air flow and rate valve.

3.2. THE COLD AIR UNIT

The purpose of this unit is to act as a refrigerator and to reduce the air from the 100°C. to a reasonable figure to keep the cabin cool, which probably means reducing the air to about +3°C.

When engine compression ratios were only about 3 or 4, the air turbine which did the work of refrigeration usually drove a compressor to provide further pressure for the turbine. The air was then inter-cooled before expanding through the turbine. Today with the higher engine compression ratios of 6, 8 or 10:1, no additional compression is required, so the turbine is made to do work on an air fan for ground primary cooling and so on.

3.3. CONTROL VALVES

The cabin air flow and temperature control is carried out by a modulating valve (Fig. 8) usually, for convenience, operated by an electric motor actuator. In many cases these valves have to withstand full engine pressure and the maximum compressor temperature. Where the valves are engine-mounted, they have to operate under high air temperatures and under engine vibration conditions. The operation of such a valve at temperatures exceeding 350°C., and without air leakage, presents quite a problem.

4. Control Methods

Basically, it is necessary to control automatically the temperature in the cabin to within certain limits, these limits again being manually adjustable over a convenient range. In principle, the sensing head in the cabin outlet is a wire-wound resistance forming one leg of a bridge circuit, with a manually-adjusted setting potentiometer in another leg of the bridge, as shown in Fig. 10. Any out-of-balance of the circuit is picked up by an amplifier, either electronic or magnetic, or a sensitive relay, which in turn transmits the signal to the control valve. A follow-up circuit coupled to the control valve is used to re-establish the electrical balance of the bridge circuit.

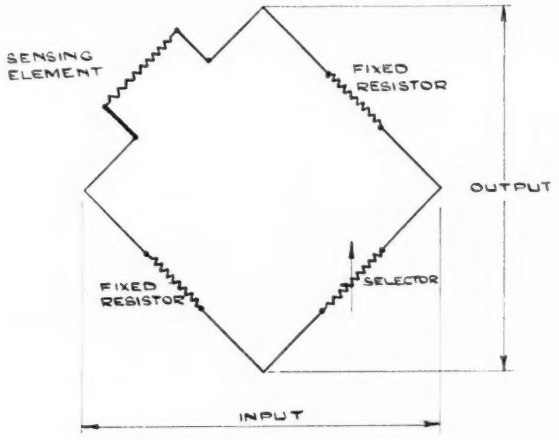


FIGURE 10. Basic control bridge circuit.

Although this illustration is in electrical terms, the same balance can also be achieved by the use of electro-pneumatic, hydraulic, or mechanical inching controls. More detailed discussion of amplifiers and inching controls will follow later, but it should be appreciated that the control of an even cabin temperature is a very special problem.

Temperature control infers the sensing of the temperature and then its correction to the specified figure required. This can be done in several ways and the first to be considered will be an Inching Control.

There are three main methods of electrical inching, all of which work on the principle of restoring the balance of the Wheatstone Bridge.

4.1. SENSITIVE RELAY

Two arms of the bridge contain sensing elements as shown in Fig. 12(*a*), while the other two arms contain a follow-up resistor and a setting potentiometer. Across the bridge is the sensitive relay which operates the electrically-actuated hot air valve. The difficulty of this circuit is to obtain a relay sufficiently robust to withstand aircraft vibration conditions and yet sensitive enough to work off the small current changes of the sensing element.

A large number of American aircraft use a variation of this circuit, the sensing element being a Thermistor. This has the characteristic of changing its resistance with temperature to a larger amount than the usual wire-wound resistance sensing element and allows the use of a fairly robust relay called a Micro-Positioner (Fig. 12(*b*)). The Thermistor is limited to a certain maximum air temperature.

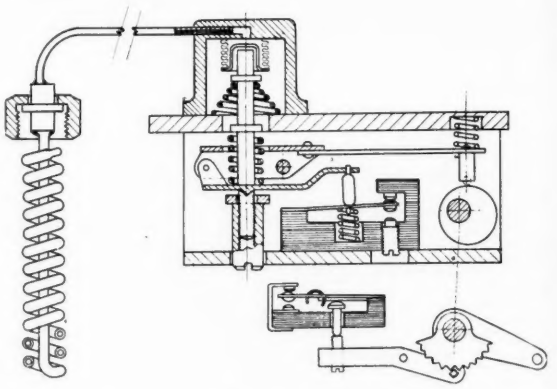


FIGURE 11. Mechanical inching control.

4.2. VALVE AMPLIFIER

This (shown in Fig. 13) is basically the same as the sensitive relay, but the sensitive relay is replaced by a three-valve amplifier giving a magnification of 2,000. The electrical follow-up is replaced by three sensing elements, one being in the cabin and two in the air duct, the first shrouded and the second unshrouded; the two in

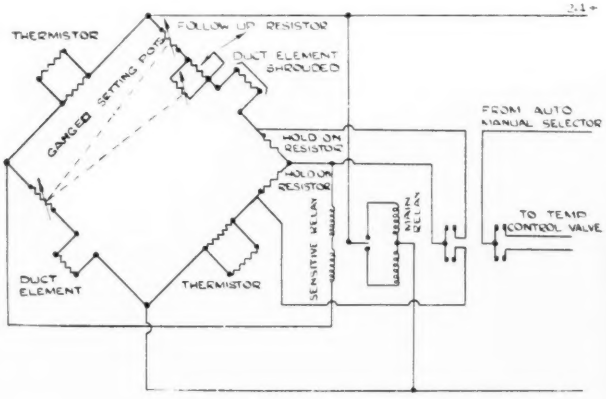


FIGURE 12(*a*). Sensitive relay control.
Controls to within ± 2·5°C. of setting point. Setting point adjustable between −5°C. and +33°C. differential 1·5°C.

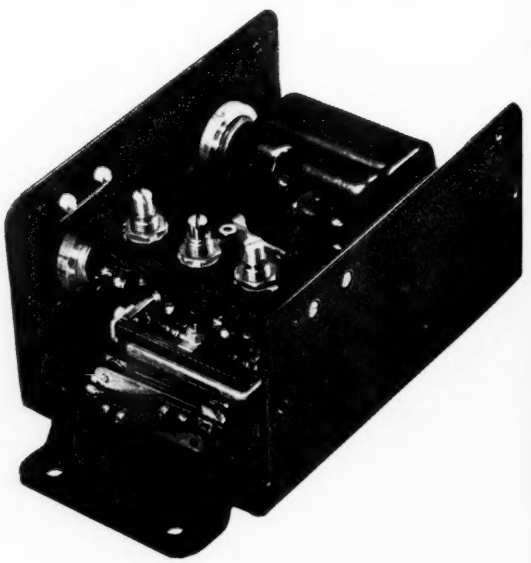


FIGURE 12(*b*) (*right*). Sensitive relay controller.

the air duct provide a measure of anticipation of temperature change.

The sensitivity of the circuit is such as to maintain cabin temperature to within $\pm 2\frac{1}{2}$°F. This method of control is employed in a large number of British civil aircraft and a typical time cycle on temperature control is shown in Fig. 14 (Ambassador).

4.3. MAGNETIC AMPLIFIER

In view of the complexity and short life of the valves in the valve amplifier system, an equivalent system has been devised incorporating magnetic transductors. This enables a robust relay to be used which is also the only moving part. This control is fitted to a number of modern military aircraft for cabin temperature control and for wing de-icing hot air control.

The ability to use a heavy duty relay instead of the micro-positioner type, as in the sensitive relay controller shown in Fig. 12(*b*), means that the hold-on resistors can be deleted. The purpose of these resistances is to ensure that when the unbalance signal operates the main current relay, a low value of resistance in the bridge circuit is cut out. This has the effect of holding the relay down for a short space of time and hence prevents any arcing of the relay contacts.

Simple magnetic amplifiers can be made to operate on single phase alternating current, although more intricate units work on 3 phase, 400 cycle, 110 volts, and are corrected for variations in both A.C. volts and frequency in such a manner that the temperature control does not vary by more than 1°C. over the whole electrical supply range.

Because of rectifier design limitations, it is necessary to install these units in regions not exceeding 70°C., or their life will be reduced.

These are the electrical devices used for amplifying the sensing signal from the cabin, engine intake or wing leading edge, and for providing the power to correct the heat input through the temperature control valve.

4.4. MECHANICAL INCHING CONTROL

The principle of this instrument is that it senses the actual temperature by a sensitive phial which operates a central electrical contact. Increase or decrease of temperature makes one or other of two circuits, one on each side of the central contact. The two contacts are mounted on a central arm which is connected to the valve, supplying the change of temperature as shown in Fig. 11. When a temperature correction is required, the sensing phial moves the central contact and makes an electrical circuit, which in turn operates the hot air valve. This valve is connected back to the inching control double contact arm which breaks the electrical circuit again.

If the new position of the hot air valve gives the necessary correction to the air temperature, then the circuit remains broken and the required temperature is obtained. In order to prevent constant starting torque being applied to the electrically actuated hot air valve, it is usual to divide the range of the inching control into a number of steps.

Such a device can only be applied when the distances between the inching control and the operating valve and sensing element are small, as in the case of engine and intake hot air de-icing. Where the distances between the components are over about 12 ft. it becomes necessary to use an electrical method of inter-connection between the components.

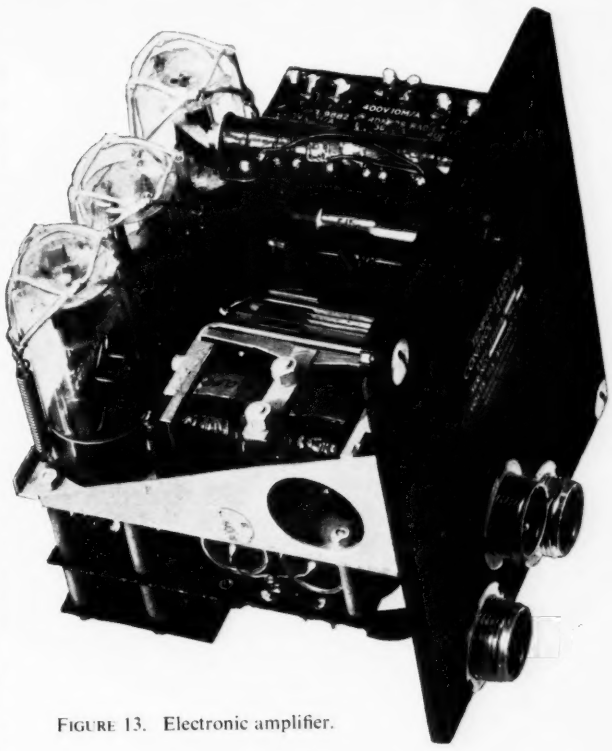


FIGURE 13. Electronic amplifier.

5. Feed-back Systems

It is necessary at this point to explain what is meant by feed-back and to show how this achieves stability.

For example: If the cabin temperature is set to 5°C. and the pilot requires 15°C., he moves the temperature control regulator (a potentiometer in the bridge circuit) to the required figure. This has the effect of putting the bridge out of balance and the cabin sensing element calls for more heat. Its resistance is too low, so it operates the relay to open the hot air valve, thus increasing the resistance of the sensing element. When the new selected temperature has been achieved, the bridge is balanced and no further alteration of the heat input is called for.

This is the ideal system but, unfortunately, in practice there is always a time lag between the sensing element calling for a change of heat flow and its actual arrival.

Early designs of temperature control system had built-in lags of 8 to 10 minutes before the signal for heat resulted in a balance being established. This was true of a large civil aircraft where the heat was regulated by controlling the cooling or heating air to the primary heat transfer unit. Such a circuit meant that the whole of the heat equivalent of the heat exchanger was affected before the temperature of the cabin air leaving the

exchanger was stabilised. Extensive duct losses further modified the final temperature of the air entering the cabin. It is obvious that if the actuator control of the heat exchanger flap is rapid (say 15 sec.) from full heat to full cold, then hunting of this control is bound to occur. A better way of controlling the heat supply is to by-pass the heat exchanger mixing the two flows. This has become modern practice.

A further improvement in control is possible by inserting a stabiliser in the bridge circuit. This, in effect, is an additional resistance, which is overwound with a heater coil. This coil is in parallel with the actuator and each time a signal is received for actuator movement, this starts and is then cancelled out by a re-balancing of the bridge resulting from the heater coil, increasing the resistance in the bridge circuit. The actuator movement is thus halted and the heater circuit broken.

Because of the time taken for the stabiliser to cool, the actuator is held in this position for a short space of time. If the bridge circuit is still out of balance after cooling, then the actuator and heater coil are again energised for a further small correction and this is repeated until balance is established. It might almost be said that the actuator is made to stop and think. "On" periods of one or two seconds may be used with "off" periods of one or two minutes if necessary.

Another way of achieving the same result is to insert into the bridge circuit additional "ductstats," shrouded and unshrouded. A change of air temperature in the duct has the immediate effect of starting a bridge correcting signal, before this is felt by the "cabinstat." This out-of-balance, however, is quickly corrected by the shrouded ductstat in the opposite bridge leg, which in time reaches the same temperature as the unshrouded unit and hence cancels the signal.

A third method of electrical feed-back uses a potentiometer in the bridge circuit. This is coupled to the controlling valve in such a way that a signal from the cabinstat requesting a change of heat supply results in the operation of the hot air control valve, which in turn mechanically changes the value of the follow-up resistance in the bridge. The new value of the resistance tends to re-establish the balance of the bridge. If this is still not correct the cabinstat starts a further pulse until the temperature called for is attained.

These methods of stabilisation are those generally employed for cabin temperature operation but a mechanical inching control has been used for many years for radiator and oil cooler temperature control and has been adopted recently for jet engine and intake surface anti-icing. This works on the principle of a signal from a sensitive phial which operates a changeover "centre

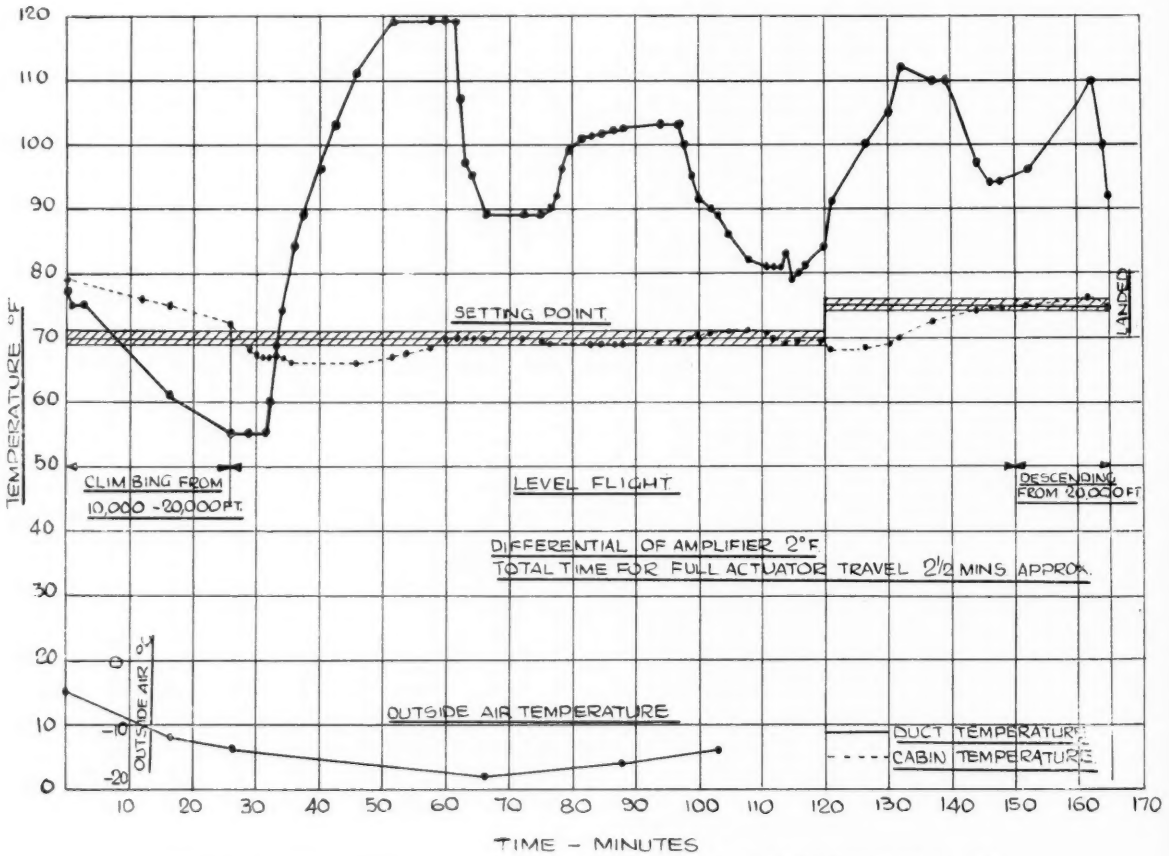


FIGURE 14. Cabin temperature and duct temperature characteristics of 30/40 seat civil aircraft.

off " switch, either to increase, or decrease, the heat supply, as already explained in Section 4.4.

Such a mechanical system sounds simple, but it has to be remembered that by virtue of the mechanical feed-back it is necessary to keep the inching control, the hot air valve, and the sensing phial, all as close together as possible and in the engine bay.

This means that the hot air valve, actuator control, and so on, must be able to operate under ambient air soak temperatures of 150°C., must be fully compensated for altitude, insensitive to engine vibrations, and still work within very close tolerances of temperature.

Figure 4 illustrates the loss of thrust or increase in fuel consumption resulting from too coarse a control, and indicates the need for very close control on air flow, in order to avoid excessive engine thrust losses.

The instrument is normally set to operate from a fully closed valve at 6°C. to fully open at about +1°C. in steps of $\frac{1}{8}$ or $\frac{1}{4}$°C. at a time, but the actual setting temperature will depend on the sampling point on the engine and it may be necessary to fix the opening of the valve anywhere between 5 and 10°C. to prevent ice formation on sensitive parts.

Development has shown the absolute necessity for the anti-icing of jet engines and the wide range of icing conditions makes it imperative that only the minimum of heat be used to prevent ice formation.

Normal maximum humidity conditions may be as high as 2 gm./m.^{3} with exceptional cases rising to 4, or even 10, gm./m.^{3} of air. If the control equipment is designed to deal with any such high figures, then it is obviously very expensive on engine thrust to cater for mild icing conditions which may be near to $\frac{1}{2}$ gm./m.^{3}, which will require the hot air valve to be only just cracked open.

6. Control Stability

An important point in feed-back control is the stability of the system. This is achieved by stabilisers or shrouded ductstats as mentioned previously and by a careful study of the rate of change of heat supply relative to time of actuator hot air valve operation. That is to say if a certain aircraft installation gives a rate of change of cabin temperature of x°/min. for a change of $3x$ in the duct supply temperature, then it will be found that the actuator time of operation of the control valve must be a function of this ratio, either directly or by one of the devices already mentioned. This is shown diagrammatically in Fig. 15.

Curve (1) shows the control valve swinging from full shut to full open and the duct temperature following in extremes of temperature. Curve (2) shows the case where the valve is gradually stabilised and with it, the temperature fluctuations die out but only over a long period of time, which means that the actuator is working hard and its life is short. Curve (3) is the ideal where the valve quickly stabilises its position and with it, the duct or cabin temperature.

It will be appreciated that every aircraft installation will have its own characteristics because the rate of cabin heat loss, the rate of heat supply from the engines,

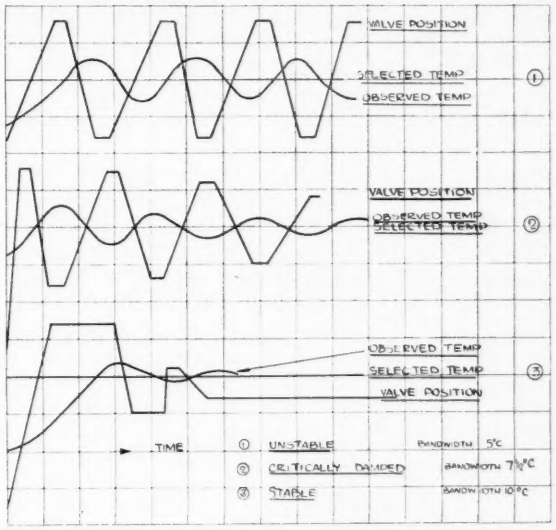


FIGURE 15. Stability diagram.

and the effectiveness of the coolers and cold air units will vary.

Further, such an explanation makes it clear that the control valve for the heat supply must be one that gives a steady change of temperature for each increment of valve movement. For this reason the gate valve type of control valve is used instead of the butterfly type.

Figure 16 shows graphically the results obtained from valves of these two types when used as modulating controllers. The ideal would be a constant rate of temperature change or of flow for the whole operation of the valve. It should be mentioned at this point that temperature control of a cabin is not always obtained by the

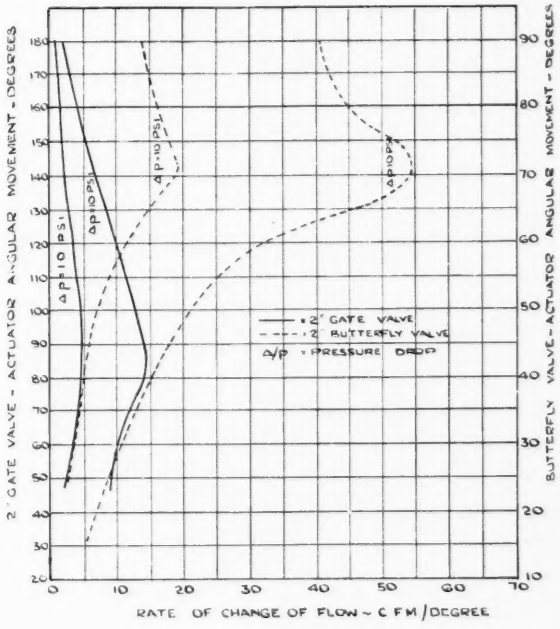

2" GATE VALVE - ACTUATOR ANGULAR MOVEMENT - DEGREES
BUTTERFLY VALVE - ACTUATOR ANGULAR MOVEMENT - DEGREES
Δp 10 PSI
Δp 10 PSI
Δp 10 PSI
Δp 10 PSI
2" GATE VALVE
2" BUTTERFLY VALVE
Δ/P = PRESSURE DROP
RATE OF CHANGE OF FLOW ~ C F M / DEGREE

FIGURE 16. Control valve characteristics.

control of the duct air temperature (as in the limit of cooling). Many cases occur where more B.Th.U.s of cooling air are required, but the air temperature has already reached the frost point.

Further reduction of temperature would result in the freezing up of the humidifier. In this case it is necessary to pass on the control of the cooling, from the temperature control valve, so that the cabinstat then modulates the actual air flow by way of the flow control equipment, as mentioned previously (Fig. 17).

Again, where temperature control is to be obtained through a valve by-passing the cold air unit, with its high maximum inlet pressures of 60-80 lb./in.^{2}, it is important that a careful matching of the valve rate of opening is made, with the final air temperature resulting from the by-pass and cold air unit flows mixing downstream.

Such are the fundamentals of automatic air temperature control. Unfortunately, there are still further complications when special cases have to be considered, for example, with civil aircraft.

7. Application to Civil Aircraft

For military aircraft it is not considered necessary to use a duplicate set of temperature control units, but for civil purposes, the coolers, cold air units, and so on, are all duplicated.

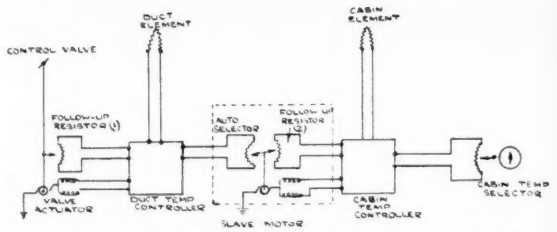
To prevent these two or more units getting out of phase and fighting each other, a synchronising circuit is introduced.

This is very simple and consists of an additional bridge circuit containing ductstats in adjacent legs. Each ductstat is fitted in the final line of its respective heat supply line before the ducts join to the common feed to the cabin. As long as there is no out-of-balance of ductstat temperature, no action is started by the bridge, but as soon as there is a lack of balance, the bridge operates a centre off double pole relay, which in turn open circuits the main control line to the actuator controlling the leading hot air valve. This forces the lagging hot air valve to take over control until the temperature balance has been re-established, when the synchronising bridge drops out of action. One important point is that the differential of this bridge must be less than that of the cabin temperature control or instability will occur. The circuit is shown in Fig. 18.

Another point of importance is that of limitation of maximum and minimum duct temperatures for reasons already stated. The principle of this is shown in Fig. 17 and is again based on the insertion of another bridge modulating circuit.

The normal cabinstat bridge operates a small slave motor instead of the main hot air valve actuator. This slave motor controls the cabinstat bridge follow-up and also a potentiometer in the second bridge, containing the ductstat over- and under-heat control. This in turn operates the main actuator hot air valve and follow-up resistor.

The duct control operates only at extremes of high or low temperature (max. 150°C., min. 2°C.) while the cabinstat controls between 35 and 5°C.



Duct control: Max. temp. 150°C. Min. temp. 2°C.
Cabin control: Max. temp. 35°C. Min. temp. 5°C.

FIGURE 17. Automatic temperature control incorporating overheat and under-heat control.

This system is partly necessary because of the extremes of engine air delivery temperatures, but partly because these high temperatures are introduced into the cabin without due mixing with re-circulation air.

8. Humidity Control

It is well known that a room can be comfortable on one day and uncomfortable on another, although the dry bulb temperature is the same in both cases. There are three reasons for this:—

(*i*) The variation of wet bulb temperature.
(*ii*) The surrounding air velocities.
(*iii*) The clothing worn.

For the purpose of this paper it will be sufficient to say that the control of humidity has become a necessary part of the temperature control of aircraft as in reality it is "effective temperature" that is required and not a given dry bulb temperature.

Clothing affects the comfort level between summer and winter in that the summer level is between 67-75°F. and the winter level 63-71°F.

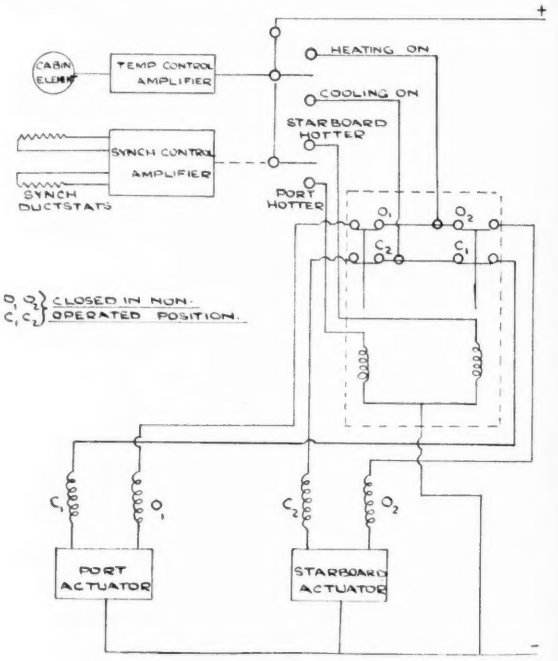


FIGURE 18. Cabin synchronising controls.

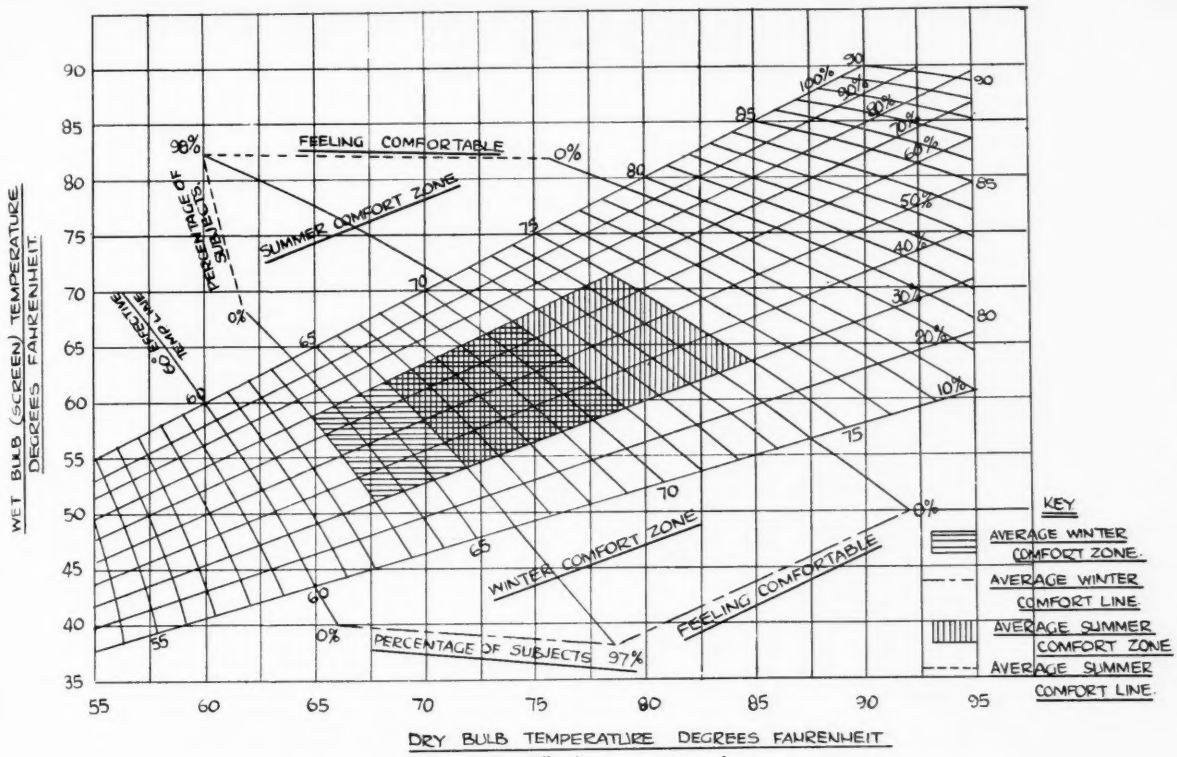


FIGURE 19. Effective temperature chart.

Very dry air places great strain on the mucous membrane which becomes dry and causes air to be drawn in through the mouth. This is important in high altitude aircraft as, because of the low temperature and density of the air used by the engines, the moisture content of the air supplied to the cabin is very low, being in the region of 5 grains of moisture per lb. of air, or even less. This air is heated and compressed but still has the same 5 grains of moisture content in it at the cabin pressure and altitude condition, that is to say the humidity is between 5-10 per cent. Fig. 19 shows the inter-relationship between humidity, wet and dry bulb temperatures and air velocity.

The body reacts to what is called on this chart "The Effective Temperature" and this is seen to be a mixture of all these factors. It will be noted that for a given effective temperature the dry bulb temperature and humidity should be changing in relation to each other or, alternatively, for a constant moisture content in grains/lb. dry air, the effective temperature is bound to change with any variation of dry bulb temperature.

Normal methods of temperature control merely govern the dry bulb temperature, but the foregoing statements indicate the need to vary the moisture content of the air, if a constant comfort level is to be obtained. This is done by a humidifier which adds moisture either automatically, or manually, as desired, and is indicated or controlled by a humidistat, which can be set to show when the humidity falls below a certain satisfactory figure and then can automatically switch in the humidifier.

Finally, it should be noted that air velocity and dry bulb temperature have considerable effect on the comfort temperature. This must be emphasised for the following reasons.

Effective temperature decreases by about 7°F. for a change of air velocity of 500 ft. per min. at constant dry bulb temperature and relative humidity, although this change is less as the dry bulb temperature increases. Thus it is an essential part of cabin conditioning to include humidifier equipment and, while this has a certain weight, the quantity of water required is many times the weight of the humidifier equipment, being 20 gallons for an eight-hour flight.

9. Windscreen Heating and De-icing

As an introduction to de-icing, the treatment of windscreen and hood temperature control provides many points of interest. It is necessary at all times to provide sufficient heat to the windscreen to prevent frosting.

The important case to consider is during the "let-down" when the whole aircraft is externally at a very low temperature and any passage through conditions of high humidity will immediately cause large scale deposits of frost. To prevent this frost deposition, many aircraft use a hot air sandwich where the external screen is as thin as possible relative to the structural requirements. This enables a maximum heat transfer from the heated inner skin to the cold external surface.

For given conditions of external air velocity, air

temperature and humidity, it can be shown that a certain temperature and flow, and hence B.Th.U., are required in the sandwich to prevent the external screen surface from reaching the frosting point.

In some cases the cabin air flow is tapped to provide the necessary source of heat. Maximum air temperature is limited because of the reduction of screen strength at high temperatures and hence, it is necessary to control the air temperature within fairly close limits and some form of temperature mixing valve is advised.

Air flow requirements for screen heating are up to 3 lb./min. per sq. ft. of screen area, with about 3,000 B.Th.U./hr. dissipation.

10. Wing Anti-icing

This is a case where it is necessary to control the quantity of air used, as excessive flow will badly affect the engine thrust. Two controls are required.

Since compressor air temperature may exceed 350°C., this temperature must be diluted to about 180°C. before it can be introduced into the leading edge of the aircraft wing. At higher temperatures the wing structure falls below its safe limit. Once this temperature figure is set, the leading edge surface is kept above the freezing point by the amount of air bled off the engine. The heat supplied is a function of the temperature of the supply as well as of the air flow.

The normal method of controlling the maximum air temperature is by using an air injector, as shown in Fig. 20. The high engine compressor pressure is used in a nozzle to suck in cold air from a leading edge rammed air intake, through a cold air inlet valve. This valve is modulated by a sensing element downstream at the wing inlet to prevent the inlet temperature exceeding the maximum allowable figure of, say, 180°. This modulation can be achieved either by an inching control, or by one of the amplifier circuits already mentioned.

The final quantity of hot air used, that is to say the B.Th.U. input to the wing, is controlled by another sensing element in the wing leading edge operating through its necessary amplifiers to the hot air valve between the engine and the air injector pump.

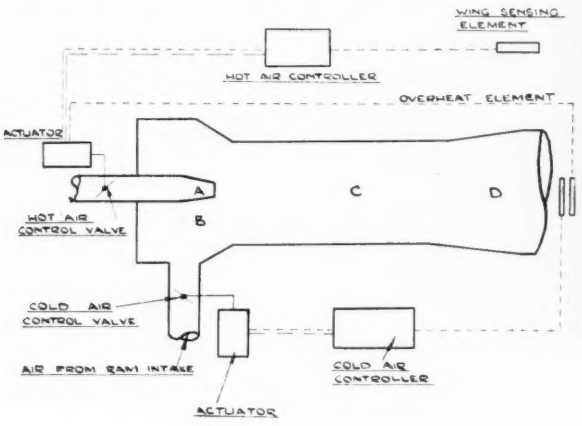


FIGURE 20. Air injector pump.

Because of the quantity of hot air required and the effect of this bleed on the compressor characteristics, an alternative method is to tap the inter-stage turbine for hot gas, although this must not be used directly for reasons of fire risks, maximum temperature limitations, and possibly corrosion of the wing; normal practice is to pass this hot gas through a heat exchanger. Here it heats rammed air, supplied from the wing leading edge, which then passes on to heat the length of the leading edge, in the same way as the method using direct hot air.

The hot gas flow to the heat exchanger is modulated by a valve controlled by the usual sensing element in the leading edge of the wing. This hot gas control operates on the wing leading edge through the medium of the heated air and the maximum air temperature once again has to be limited.

11. Electrical Methods of De-icing

All electrical methods of heating rely on heater elements embedded in the windscreen, wing leading edge pads, or similar devices in air intakes or propellers. Fig. 24 shows a photograph of icing occurring on an aircraft fin. This was a case of instantaneous icing at −25°C., 0·5 gm./m.^{3}, with 30 micron drop size.

Owing to limitations in the amount of electrical energy available at any one instant, the heat has to be cycled, so that the controller usually consists of a constant speed motor operating a series of circuits in a known sequence. Examples of this are to be found in various new aircraft, such as the propellers of the Ambassador, the Viscount propeller and engine intake and the Britannia fin and tailplane.

Normally, there is a fixed wattage heat input for a given time period, the total time cycle just covering the complete circuit of all the pads. This system gives only

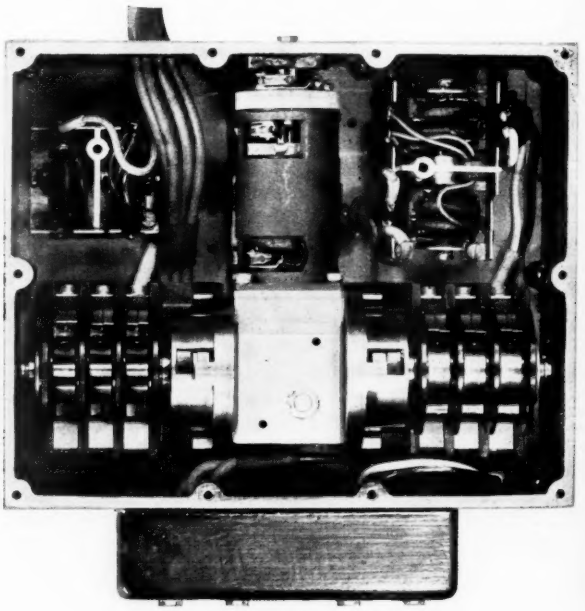


FIGURE 21. Cyclic de-icing switch.

one rate of heating which is often inadequate for the wider range of flight and ice conditions liable to be encountered.

The second method is to use a two-speed cycling motor so that the cycles of heating can be doubled in a given space of time, although the amount of electrical heating in that time period is no more.

The third method is to use an infinitely variable time of heat supply, so that it can be adjusted to meet any desired requirement and is the only way of giving the close control desired. This is typical of the Britannia cyclic de-icing switch.

Since 12-18 watts/in.^{2} are required to prevent icing under certain flight conditions, it is obvious that some control must be exercised or the pads will burn out if used on the ground with no forward speed to cool them.

Overheat switches can be incorporated in the pads. These signal back through a sensitive relay circuit to cut off the supply current whenever the maximum pad temperature is reached. Such circuits are used for controlling the heat supply to the Comet generator air intakes and, also, to the windscreen de-icing of the Britannia.

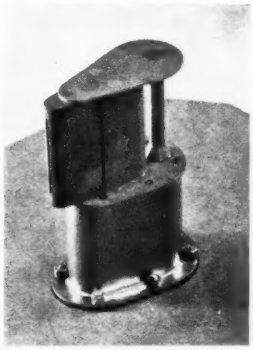


FIGURE 23. Icing indicator.

Figure 21 shows a photograph of the Viscount Cyclic De-Icing Switch. This cycles the heat to air intake and the propeller blades and has also two separate speeds, to the time sequence shown in Fig. 22. In all these cases, the effectiveness of the heating pad is determined by the time it is on, and not by the change in wattage per unit of time.

12. Icing Indicators

The subject of Anti-Icing of engines and aircraft is incomplete, unless a solution can be found to the detection of ice.

It is no use being able to prevent or remove ice unless its presence can be detected in time and appropriate action taken, as its effect may be tragic, and, in the engine case, rapid.

It has already been shown that both engine and wing de-icing equipment are available, but it is also clear that it is extremely wasteful to use this equipment when ice is not present. This may be from 85 to 95 per cent. of an aircraft life.

As a result, icing indicators (Fig. 23) have been

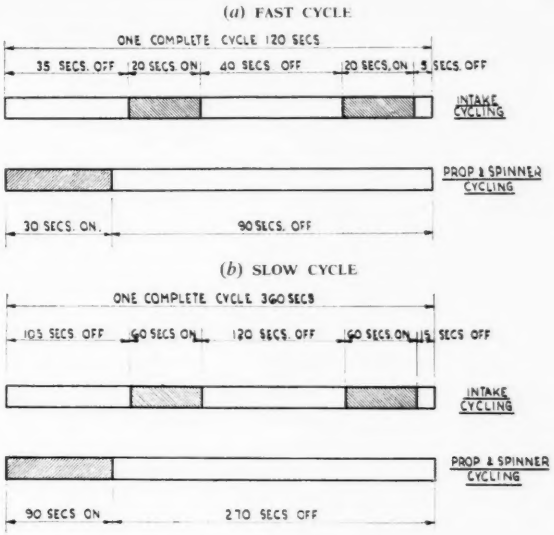


FIGURE 22. Nominal timing diagrams.

developed which operate in series with the air thermometer to start the Anti-Icing equipment only in icing conditions.

It can be argued that Ice Anticipators are really what is required, as once ice is formed it may take twice as much heat to remove it as would have been required merely to prevent the original deposit. On the other hand, an ice anticipator may often switch on the Anti-Icing equipment and ice may never be found.

Again, heavy icing may occur as a result of the let-down of a very cold aircraft through cloud slightly above icing temperatures. Neither an indicator nor anticipator would necessarily detect this condition, so that much thought still needs to be given to this subject before it can be said that a satisfactory solution has been found to the problem of Ice Detection.

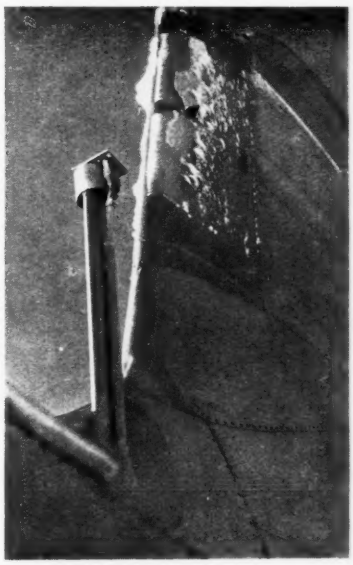


FIGURE 24. Icing on an aircraft fin.

13. The Future

The advent of the jet engine has made it necessary to reconsider the science of temperature control and this is going to extend rapidly as aircraft altitudes, speeds and engine compression ratios increase.

The economic use of the jet engine improves with altitude and one can visualise civil aircraft of the near future flying at 60,000 ft. at Mach numbers between one and two. Engine compression ratios will be about 10:1.

What does this mean in terms of temperature control? A Mach number of one gives a ram compression temperature rise of 50°C., while $M=2$ gives 200°C. This means that if the outside air temperature is −56°C. then the corresponding engine inlet temperatures are approximately −6°C. and +146°C., respectively.

At 60,000 ft. the absolute pressure is about one lb./in.², while the cabin pressure required is over 10 lb./in.². This means that full engine compression ratio must be used to pressurise a civil aircraft cabin at altitude.

The corollary is also of interest. These high compression ratios result in compressor temperature rises of 350°C., so that the air leaving the compressor for cabin pressurising will be around 350°C. or 600°C. for Mach numbers of 1 and 2, respectively.

It will thus be seen that the problem is one of temperature reduction before it can be used in the cabin. Implied in this is the enormous pressure the system would have to withstand at sea level, and the first step to control such a state of affairs would seem to be the supply of air off the engine at compression ratios inversely proportional to altitude, that is to say a control giving maximum compression ratios, at aircraft ceiling, falling to a certain minimum value at about 10,000 ft. This would reduce the maximum pressures to which the system is exposed, but it will not reduce the maximum altitude temperatures as quoted and hence, any heat exchangers used must be capable of operating with through temperatures from 400-600°C. and cooling air from 0-200°C.

It is obvious that for $M=2$, a new approach is required as the present coolers and cold air units are quite incapable of giving the necessary temperature reduction, or possibly even being strong enough to withstand the high temperature.

Vortex tubes have not been mentioned but it is probable that, with the higher engine compression ratios now contemplated, this method may shortly become a rival to the normal cold air unit. German reports indicate that the equivalent cooling efficiencies of cold air units are obtained if 100 lb./in.² air pressure is available.

The future may offer some simplification as, at high speeds, there is no anti-icing problem at all, but the icing problem will still arise in the let-down and take-off cases.

14. Recommendations and Conclusions

1. Compressed air off jet engines forms the natural source of heat supply.
2. Engine designers should incorporate in their compressors sufficient margin of air bleed to cover all aircraft demands.
   Typical figures are given in Table II.

TABLE II

	Single-engine aircraft	*Twin-engine aircraft*	*4- or more engine aircraft*	*Remarks*
Cabin flow: lb/min.	10	20	50 to 100	Constant
Accessories	10	10	10	Constant
Windscreen	3 to 6	10	10	In icing only
Engine anti-ice	50 to 100	50 to 100	50 to 100	In icing only
Wing anti-ice per engine	250 max.	250 max.	250 max.	In icing only
Total: lb./min.	275	390	470	

3. Since normally cabin air flow is a small proportion of the total bleed required from the engines, cabin air flow requirements should be generous, as the temperature changes for given heat loads need not then be extremes and could simplify the over-ride controls of either temperature or flood flow and delete increased refrigeration air flow.
4. The simplest circuit diagram giving full heat control is that using a single four-way valve, as shown in Fig. 8; this gives the minimum of heat lag and only one control valve.
5. Coolers and Cold Air Units and valves must be made to operate at engine pressures up to 200 lb./in.² and temperatures of 400°C.
6. It is unlikely that engine manufacturers will encourage the idea of variable pressure tapping of of compressors, nor is it possible unless pressure is available at sea level to drive the C.A.U.
7. Automatic Cabin Temperature Control is an essential part of military jet aircraft.
8. It is probable that hot air anti-icing of engines and aircraft will be the method employed in the future, in preference to electrical pad heaters, as the control of the hot air is easier over the wide range of required conditions of flight.
9. The automatic control of de-icing is no different from cabin temperature control, except for the necessity of anticipation.
10. Simplification of such control systems should be the constant ideal, but it must be remembered that the final simplification is achieved when the pilot of a fighter only has his guns and his aircraft controls to consider.
    If the automatic cabin and icing controls are effective and reliable these two factors are of more military value than simplification, if by this is meant pilot operation of the components.

Acknowledgment

The author acknowledges and thanks the Managing Director of Teddington Controls Ltd. for permission to publish the information contained in the paper, and his friends in the Industry for their suggestions and advice.

TECHNICAL NOTES

The increasing flood of technical information makes it difficult to publish even abstracts of such information and it has become still more difficult to publish technical items of information which do not reach the status of full-length papers.

Under this general heading of TECHNICAL NOTES it is hoped that members of the Society, and indeed all those who read THE JOURNAL, *will help in contributing just those very items of useful information which normally might not see the light of the printed page.*

There will be no set form for these Notes. They may be illustrated or not. They can be short papers of a thousand or two thousand words; or abstracts and comments upon unpublished papers or upon published papers with a limited circulation; or notes of some interim results of research in hand and notes for further research; or in the form of a letter raising technical points or asking technical questions; or letters commenting on Notes already published.

These pages are intended to be a technical forum where members can argue and discuss; where they can inform and be informed; and pass on their own experience, or air their technical difficulties. Contributions will be published as soon as possible after they are received and will be eligible for JOURNAL *Premium Awards.*

No member need ever say that his particular subject does not get discussed in the pages of THE JOURNAL. *He can always raise it himself, for these pages are his pages.*

The notes published this month deal mainly with structural subjects, although that of R. Tatham has a wide general application. The particular example used by Tatham has been studied very closely and there is no doubt that, if a slight loss of accuracy can be accepted, the method will give a saving in time over the alternative successive approximation method in this particular example. The loss of accuracy is due to slight non-linearity of the relationships; with linearity there is no inherent loss of accuracy in the method.—THE EDITOR.

The Fatigue Properties of Z-Section Test Pieces Completely Machined from an Aluminium Alloy Extrusion Conforming to D.T.D. 364B

by

G. FORREST, B.Sc., A.M.I.Mech.E., K. W. GUNN, A.R.S.M., B.Sc., AND A. R. WOODWARD, B.Sc.
(Aluminium Laboratories Limited, Banbury)

IN 1949 F. H. Pollicutt, in the course of a discussion on a paper presented by P. B. Walker to the Royal Aeronautical Society[1], reported fatigue test results which indicated that when the aluminium alloy conforming to specification D.T.D.364 was tested, under axial loads, in the form of Z-sections, its fatigue properties were extremely low. Z-sections with unmachined surfaces and even Z-sections with completely machined surfaces failed after short endurances at stress ranges under which small polished round test pieces would not have failed even after hundreds of millions of cycles. Pollicutt, in discussing these low values, advised that great caution should be exercised in their interpretation, warning equally against an unqualified acceptance of the testing technique and a too facile acceptance of small polished round bar test results.

Since the publication of Pollicutt's results, several other investigators in the United Kingdom have conducted tests which, although not identical with the original tests, were concerned with the same problem. The results of their work have been summarised elsewhere[2] by the present authors and it is sufficient here to record that whereas all investigators found a serious reduction of fatigue strength associated with the presence of an unmachined surface—up to 50 per cent. loss in strength at ten million cycles endurance—the loss was far less than that reported by Pollicutt.

No direct comparison could be made between Pollicutt's results and those obtained by later investigators because these further tests had been made with other shapes and sizes of test pieces, other modes of stressing and other types of testing machines. It was therefore decided to repeat as closely as possible the original tests on fully machined Z-section test pieces. Fully machined specimens were chosen since it was considered that the interpretation of results would be more straightforward with these test pieces than with test pieces containing the unmachined surface, or with additional features causing stress concentrations.

In view of the difficulties in making axial load tests, the designs of the test pieces and the precautions taken to ensure axiality of loading are described in detail in an appendix to this note.

This investigation was made at the request of the Northern Aluminium Company Ltd.

GENERAL ACCOUNT OF TESTS

Axial load fatigue tests (Fig. 1) were made on Z-section test pieces machined from solid bar which conformed to specification D.T.D.364B. The designs of the test pieces are illustrated in Figs. 2 and 3, where the

Received January 1953

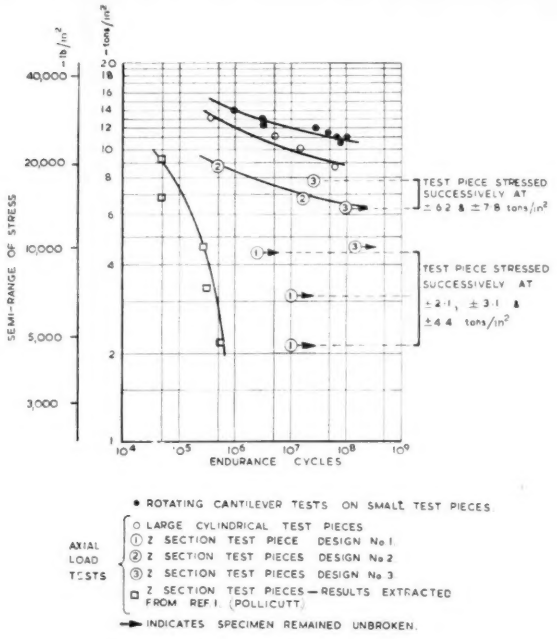


FIGURE 1. Fatigue test results on test pieces machined from aluminium alloy extrusions conforming to specification D.T.D.364.

test piece used by Pollicutt is also shown for comparison. Similar tests (Fig. 1) were made on round section test pieces whose longitudinal elastic characteristics were similar to those of the Z-section test pieces. These test pieces are also illustrated in Figs. 2 and 3.

The tests were all* conducted under a mean stress of 5·9 tons/in.² (13,300 lb./in.²) in a 10 ton Amsler "Vibrophore" machine. The accuracy of machining, the static stress distributions in the test pieces and the dynamic calibration of the machine are described in detail in the Appendix.

The positions of the fractures in the Z-section test pieces are shown diagrammatically in Fig. 4.

CONCLUSION

It is concluded from these tests that the fatigue resistance of this sample of D.T.D.364B material in the form of fully machined Z-sections, although some 20-30 per cent. below that of cylindrical test pieces, is still reasonably high and in no way confirms low test results previously published.

The difference of 20-30 per cent. between the fatigue strengths of the Z-sections and the cylindrical test pieces is still considerable and the authors are not satisfied that the whole of this difference may safely be attributed to the variations of stress across the Z-sections which were shown to exist under static loading conditions.

*With the exception of the test piece stressed under a semi-range of stress of 8·9 tons/in.² (20,000 lb./in.²)—this was tested under a mean stress of 8·9 tons/in.² (20,000 lb./in.²).

ACKNOWLEDGMENT

The authors' thanks are due to W. G. Halford for his exercise of skill and ingenuity in machining the test pieces.

REFERENCES

1. POLLICUTT, F. H. (1949). Discussion to paper on Fatigue of Aircraft Structures by P. B. Walker. *Journal of the Royal Aeronautical Society* 1949, p. 781.
2. FORREST, G., GUNN, K. and WOODWARD, A. R. The Fatigue Properties of Unmachined and Machined Extruded Sections. Ministry of Supply Scientific and Technical Memorandum No. 7/52.
3. RUSSENBERGER, M. (1945). A Dynamic Tension-Compression Testing Machine for the Determination of the Fatigue Limit and the Damping Capacity of Materials. *Schweiz Archiv*, 1945, 11 (2) 33-42.
4. RUSSELL, A. E. (1949). Aircraft Materials from the Designer's Point of View. *Second International Aeronautical Conference*. New York, 1949, p. 231.

APPENDIX

Detailed Account of the Testing Technique

1. MATERIAL USED IN THE INVESTIGATION

The chemical composition and the tensile properties of the sample of 3½ in. diameter extruded stock conforming to specification D.T.D.364B used in the investigation are quoted in Tables I and II. The results of rotating cantilever fatigue tests, using test pieces of dimensions shown in Fig. 2, are illustrated in Fig. 1. The micro- and macro-structures were normal for the alloy and although a coarse grain outer band was present it was sufficiently small to enable all test pieces to be obtained from the fine grain core.

The results of the preliminary examination confirmed that this sample was fairly representative of material supplied to this specification under normal production conditions.

TABLE I

CHEMICAL ANALYSIS OF 3½ IN. DIAMETER BAR CONFORMING TO SPECIFICATION D.T.D. 364B

Cu%	Mg%	Si%	Fe%	Mn%	Ti%
4·42	0·44	0·79	0·40	0·76	0·012

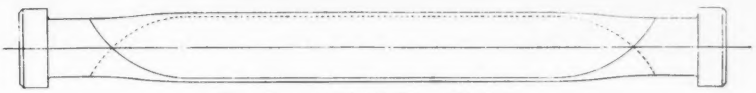
2. TESTING MACHINE

All the fatigue tests were conducted at frequencies of about 9,000 cycles/min. in a 10 ton Amsler Vibrophore axial load fatigue testing machine, the principle

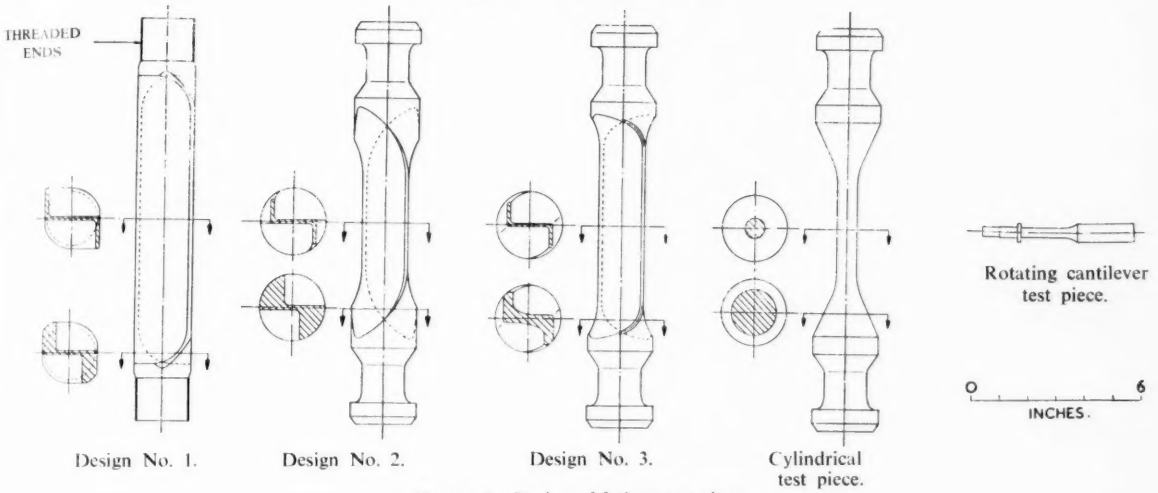
TABLE II

CONTROL TENSILE TESTS ON 3½ IN. DIAMETER BAR CONFORMING TO SPECIFICATION D.T.D. 364B

	0·1 *per cent proof stress* tons/in.²	*Ultimate tensile stress* tons/in.²	*Elongation per cent on* $4\sqrt{area}$
Test piece taken from the middle of the section	28·25	33·9	11
Test piece taken from near to the outside of the section	28·85	35·25	11



Test piece used by Pollicutt (Ref. 4).



Design No. 1. Design No. 2. Design No. 3. Cylindrical test piece.

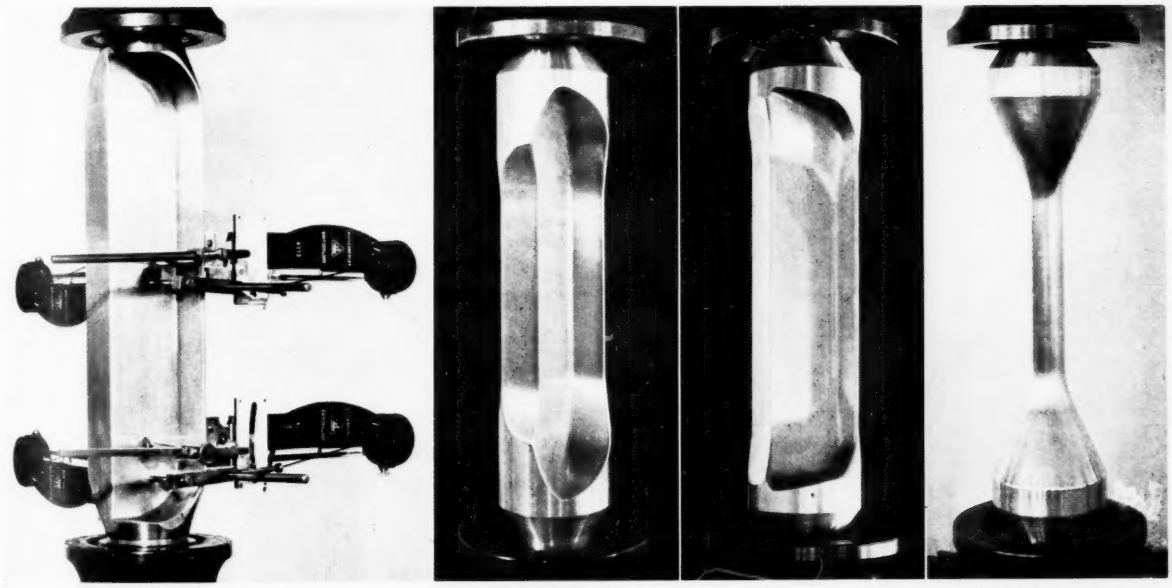
FIGURE 2. Design of fatigue test pieces.

of which has been described by Russenberger[3]. This machine operates on resonance at the natural frequency of the vibrating elements which is governed, to some extent, by the elastic characteristics of the test piece. The amplitude of the load is controlled by means of a photo-electric amplitude regulating device, which is itself controlled by a dynamometer on the machine.

3. TEST PIECE DESIGN

It was not possible in the present tests to use a test piece identical with that used by Pollicutt[4], since the machining capacity available to the authors limited the overall length of the test pieces to 14 in., whereas the original test pieces were 25 in. long. Moreover, except for the first test piece with screwed ends (*see* Fig. 2) the cross section dimensions of the test pieces had to be limited to a circumscribing circle of 2·3 in. diameter, in order to conform to the space available in the chucks of the testing machine.

Quite apart from considerations of similitude to Pollicutt's test piece, the ideal test piece would be one with a long gauge length, with the parallel portion of



Design No. 1. Design No. 2. Design No. 3. Cylindrical test piece.

FIGURE 3. Fatigue test pieces.

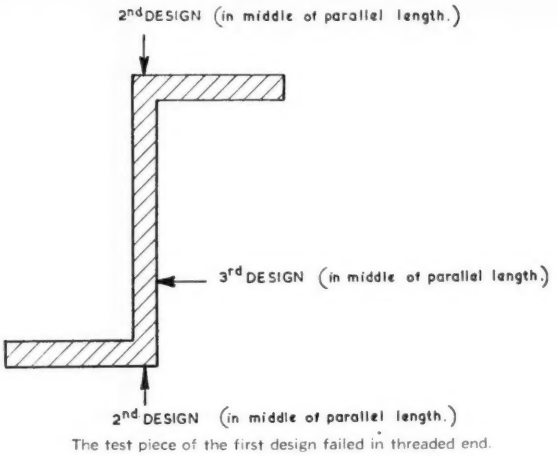

2nd DESIGN (in middle of parallel length.)
3rd DESIGN (in middle of parallel length.)
2nd DESIGN (in middle of parallel length.)
The test piece of the first design failed in threaded end.

FIGURE 4. Positions of origins of failure in Z-section test pieces.

uniform length over the whole cross section and with uniform increase of thickness in all parts of the cross section at the fillets joining the test portion to the enlarged ends. This would ensure uniform transfer of the loads from the enlarged ends to the test section and uniform distribution of stress across the test section. Of the several designs of test piece (*see* Fig. 2) which were tested, none fully met this ideal specification but all provided information of value in assessing the effect of test piece form.

4. ACCURACY OF MACHINING

The enlarged ends of the Z-section test pieces were turned between centres and the degree of eccentricity of the test length of each test piece was determined by supporting the test piece between the centres above a lathe bed and traversing the surfaces with a dial gauge reading to one ten thousandth of an inch. The maximum taper of the depth of the web along the length of any test piece was 0·003 in.; the maximum difference in the distances between the flanges and the axis of the enlarged ends was 0·002 in.; the maximum difference in the distances between the opposite parallel surfaces of the web and the axis of the enlarged ends was 0·0015 in.

The cylindrical test pieces were turned entirely between centres, thus ensuring that the test length and the ends were co-axial.

TABLE III

DYNAMIC CALIBRATION OF LOAD GAUGE ON THE MACHINE. CYLINDRICAL TEST PIECE WITH FOUR ELECTRICAL RESISTANCE STRAIN GAUGES ATTACHED*

Load range from dynamometer reading	*Strain reading—per cent. of average static strain*				
	Gauge No. 1	*Gauge No.* 2	*Gauge No.* 3	*Gauge No.* 4	*Average*
Static loading +7 tons/−2 tons	100	102	100	98	100
Dynamic loading +7 tons/−2 tons (mean load 2·5 tons)	100	97	97	97	98

*Position of gauges in the section

5. CALIBRATION OF THE FATIGUE TESTING MACHINE AND THE DETERMINATION OF THE STRESS DISTRIBUTION IN THE TEST PIECES

For a complete calibration it was necessary to determine the accuracy of the machine's load gauge under static and dynamic loading and to examine the distribution of the stresses under dynamic loading in the Z-section.

Static calibration of the load gauge

The load gauge of the fatigue testing machine was calibrated statically by determining Young's modulus of the material on cylindrical test pieces in the machine and in an Amsler tensile testing machine. The values obtained lay within the range of experimental results normally obtained with this material and so, over the range employed (2 tons), the load gauge was considered to be accurate, statically, to within ±2 per cent.

Dynamic calibration of the load gauge

Four electrical resistance strain gauges were stuck to a cylindrical test piece which was mounted in the fatigue testing machine and loaded statically. Readings obtained on a Furzehill oscilloscope were noted, together with the corresponding load gauge readings on the machine. Since the load gauge had been shown to be accurate to within ± 2 per cent. this comparison was, in effect, a static calibration of the strain gauges.

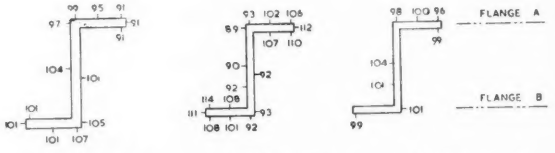


FIGURE 5. Stress distributions in three designs of Z-section test pieces. Huggenberger extensometers attached to middle of parallel lengths. Stresses quoted on the figure are expressed as a percentage of the average applied stress.

The cylindrical test piece was then stressed dynamically under several ranges of load and the corresponding oscilloscope readings were again compared with the testing machine load gauge readings. The average strain gauge readings under static loads differed from the average readings under the corresponding dynamic loads by 2 per cent. (*see* Table III), which is within the combined errors expected from the strain gauges and the oscilloscope.

There is a remote possibility that the dynamic characteristics of both the load gauge and the strain gauges differ from their static characteristics by equal amounts. This error would not be revealed by the direct comparison of the static and dynamic load gauge

TABLE IV

ESTIMATE OF DYNAMIC STRESSES INDUCED IN THE Z-SECTION TEST PIECE (DESIGN NO. 3) WITH ELECTRICAL RESISTANCE STRAIN GAUGES ATTACHED TO EACH FLANGE

Load range from dynamometer reading	*Strain reading—per cent. of average static strain*		
	Flange A	*Flange B*	*Average*
Static loading +4 tons/0 tons	100	100	100
Dynamic loading +4 tons/0 tons (mean load 2 tons)	98	102	100

and strain gauge readings. Apart from this most unlikely event* there is no reason to believe that the calibration of the load gauge by the manufacturers of the machine is in any way in error.

Distribution of stress in the Z-section test pieces

The stress distribution across the Z-section test pieces was determined under static loads by mounting Huggenberger extensometers (one inch gauge length and magnification × 1,230) at various stations across the test pieces—*see* Figs. 3 and 5. The maximum loads applied were in every case less than the mean load applied during the dynamic tests. The stress distributions are illustrated in Fig. 5 where the stresses are expressed as percentages of the average stresses in the whole cross sections. It will be seen that in the third design of test piece the stress distribution was fairly uniform across the test section. The stresses did not vary from the average by more than 5 per cent. (the maximum difference was between the stresses in the flanges and the web) and the stresses in both flanges were almost identical, showing that the test piece was loaded axially.

Strain gauges were stuck to the flanges of a test piece of the third design; the strains recorded under dynamic and static loads were compared and found to differ by ± 2 per cent. (*see* Table IV). These results also showed that under dynamic conditions the test piece was loaded axially within close limits.

6. SUMMARY OF TESTING TECHNIQUE

No evidence has been obtained which shows that the stresses induced in the Z-section test pieces differed from the nominal value by more than ± 10 per cent. (a figure which includes errors in the load gauge, eccentricity in loading, errors in the strain gauge sensitivity factor and errors in the measurement of strain recorded on an oscilloscope). It is probable that this value of ± 10 per cent. is an extreme limit and that the stresses induced in the section, apart from possible indeterminate local stresses, were much closer to the nominal values.

*Subsequent tests using other loading systems have confirmed that the total errors in resistance strain gauge readings under dynamic loads are within ± 5 per cent.

An Application of Carpet and Lattice Plotting

by

R. TATHAM, B.A., A.F.R.Ae.S.

(*Stress Office, Saunders-Roe Ltd.*)

THE CARPET and lattice methods of plotting the relationship between three and four variables respectively, developed by R. F. Sargent, of the National Physical Laboratory, have been described previously by A. H. Yates[1], who gave examples related to the presentation of aerodynamic and engine performance data. Outside these fields there appears to be still some lack of appreciation of the usefulness of this form of graphical representation, although it is capable of wide application. The writer has found both carpet and lattice plotting of great value in connection with the preparation of structures data sheets, and is convinced that interpolation is generally rendered easier and more accurate if graphical data are presented in this way. In one particular instance it was found possible to develop a nomogram in the form of an "extended lattice" plot, which gave in graphical form a direct solution to a set of equations which could be solved otherwise only by continuous approximation. Following consideration by the Structures Committee of the Royal Aeronautical Society of a report containing draft data sheets on diagonal tension fields in curved panels, of which this nomogram was part, it was suggested that a brief note describing the development of this particular plot might stimulate interest in this form of presentation. Although the procedure is quite general, the final plot is, of course, peculiar to the particular problem considered and, for convenience, this note is confined to this one instance, dealing with the relationship of certain parameters affecting the stresses developed in diagonal tension fields in curved panels, as discussed by Kuhn and Griffith[2] and later by Kuhn, Peterson and Levin[3], [4].

Received January 1953

NOTATION

A_s stringer area
A_r ring area
d ring spacing
h stringer spacing
k diagonal tension coefficient
R radius of curvature of panel
t plate thickness
α angle of diagonal tension

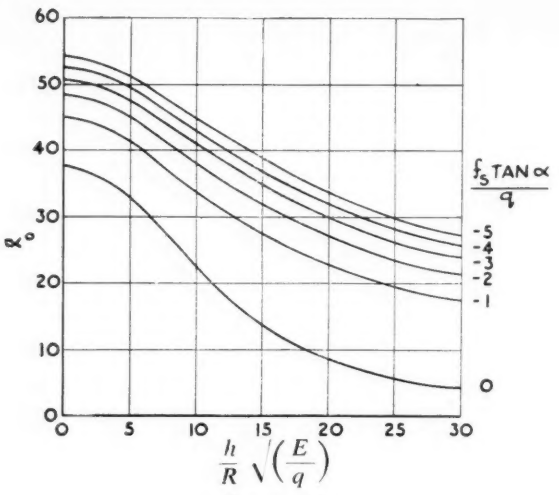


FIGURE 1(*a*).

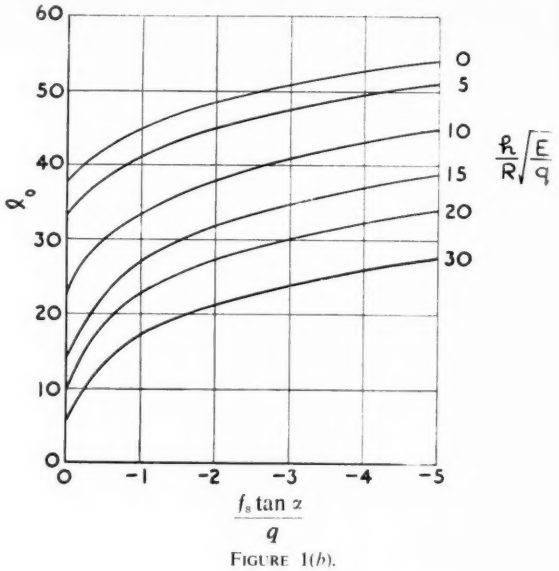


FIGURE 1(*b*).

f_r compressive stress in ring
f_s compressive stress in stringer
q shear stress in plate
q_b buckling shear stress

THE DEVELOPMENT OF THE NOMOGRAM

During an investigation by the writer into the preparation of data sheets on the effects of diagonal tension fields in curved panels, consideration was given to the presentation of the data sheets in carpet and lattice form. The procedure developed by Kuhn and Griffith[2] involves the solution of a set of equations relating the quantities α, k, f_r, f_s, q, and the panel dimensions; the set of equations is insufficient for direct solution, and a method of continuous approximation is suggested. However, the adoption of carpet and lattice plotting led to a direct graphical solution giving fair accuracy within the range of parameters covered by the experimental data of Ref. 2.

The solution consists of determining the values of α corresponding to values of the parameters k, $(f_s \tan \alpha)/q$, $(f_r \cot \alpha)/q$, and $(h/R)\sqrt{(E/q)}$. The values of $(f_s \tan \alpha)/q$ and $(f_r \cot \alpha)/q$ are determined from equations relating them to k and the ratios $A_s/(ht)$ and $A_r/(dt)$, k being dependent on q/q_b and the panel dimensions.

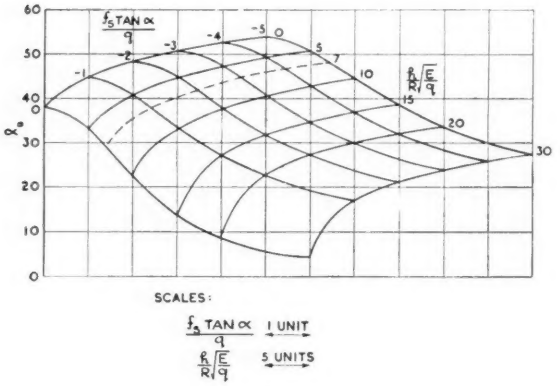


FIGURE 2.

If constant values are assigned to two of these parameters, say k and $(f_r \cot \alpha)/q$, it is possible to plot a family of curves showing the variation of α with either $(f_s \tan \alpha)/q$ or $(h/R)\sqrt{(E/q)}$ for constant values of the other of these two parameters. Typical families of curves are shown in Figs. 1(*a*) and 1(*b*), which have been drawn for $k=0$ and $(f_r \cot \alpha)/q = -1$. These two families of curves are shown combined in one carpet plot in Fig. 2. It will be observed that the carpet is constructed merely by plotting successive curves of one family with reference to an origin of co-ordinates which is moved, for each curve, a distance horizontally proportional to the constant for which the curve is drawn. The carpet plot provides the necessary "cross-plots" for interpolation, and it is a simple matter to draw intermediate curves if desired. For example, the dotted curve is drawn for $(h/R)\sqrt{(E/q)}=7$, merely by joining up points corresponding to this value on each of the curves drawn for constant $(f_s \tan \alpha)/q$. Similarly, a curve for an intermediate value of $(f_s \tan \alpha)/q$ could be drawn by joining up corresponding points on the curves drawn for constant $(h/R)\sqrt{(E/q)}$.

Similar carpets may be drawn for other values of k and $(f_r \cot \alpha)/q$. Just as a carpet is obtained from a family of curves by staggering the origins of the separate curves, so a lattice is obtained from a family of carpets by staggering the basic origins of the separate carpets. The stagger may be horizontal, but it may sometimes be found desirable for clarity to stagger diagonally. As an example, the lattice for $(f_r \cot \alpha)/q = -1$ *is* shown in Fig. 3, the the origin of co-ordinates being displaced for each carpet by an amount proportional to the value of k for which the carpet is drawn. The basic axes for the carpet corresponding to $k=0{\cdot}5$ are AB and AC. In this case the carpets are staggered diagonally, but it is more

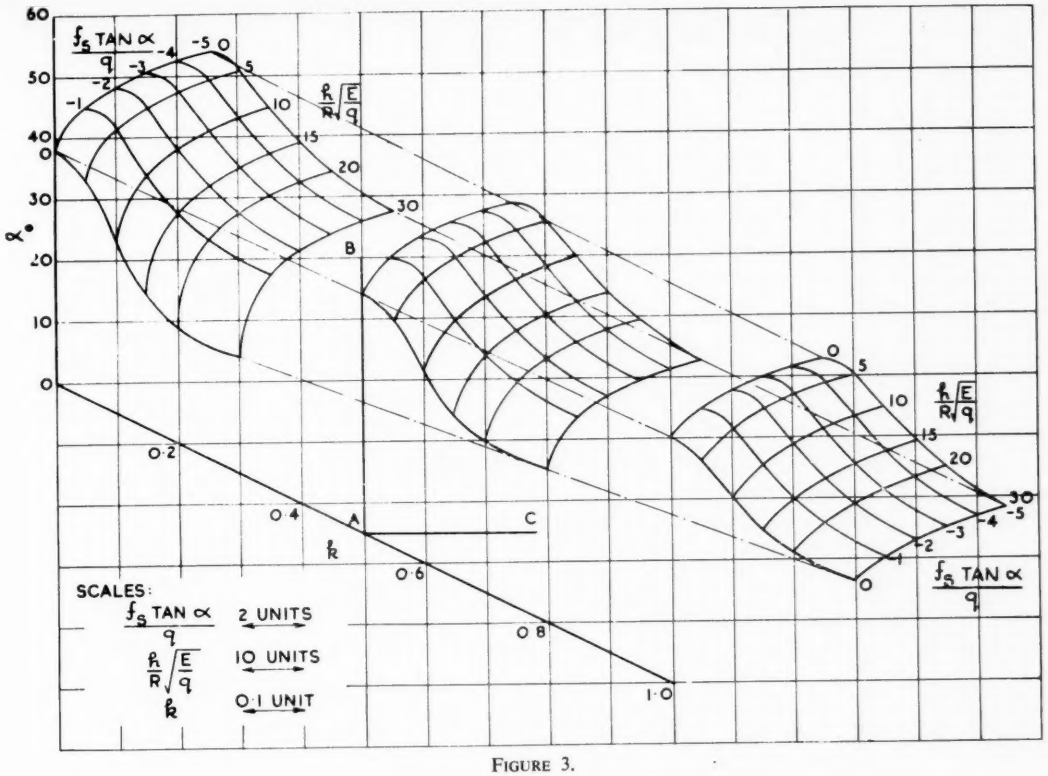


FIGURE 3.

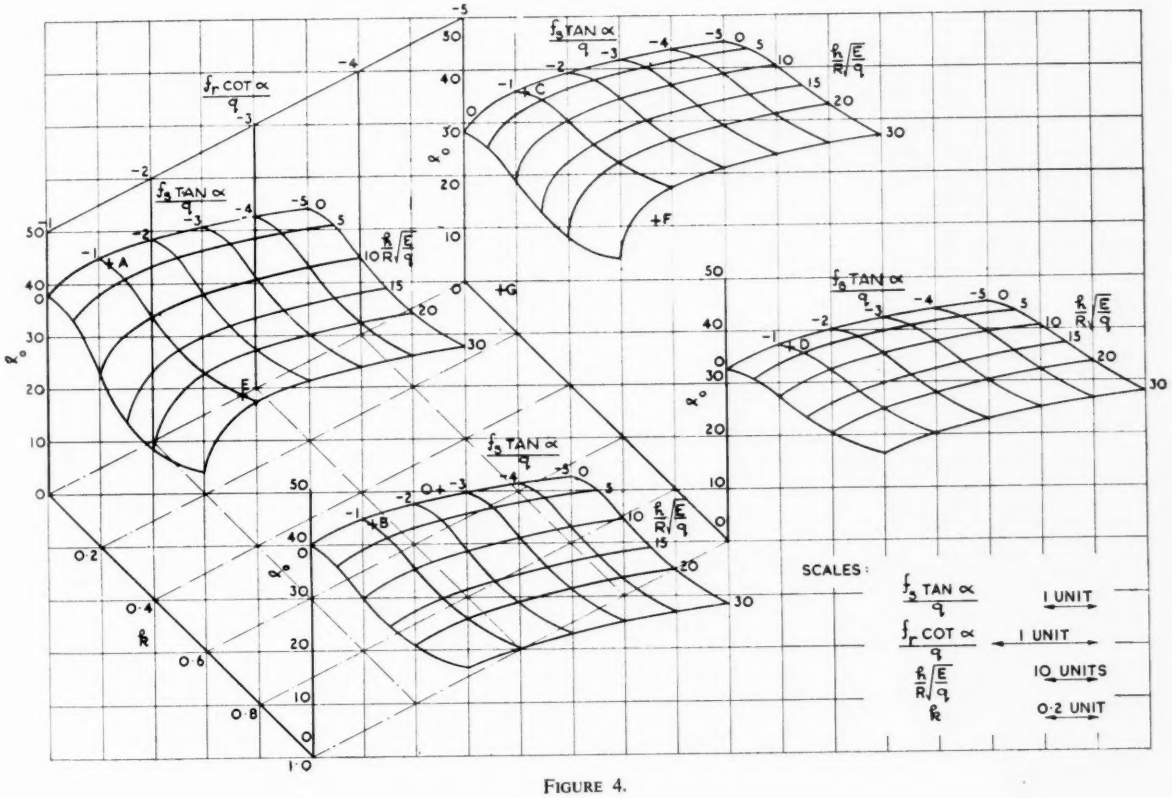


FIGURE 4.

convenient to think in terms of the horizontal displacement of the origin as indicated by the scale for k quoted on the figure. In this particular instance, it was observed that corresponding points on the separate carpets lay on straight lines in the lattice plot. Hence it is necessary to draw only the end carpets, as a point corresponding to an intermediate value of k may then be obtained by a linear interpolation along the straight line joining the appropriate points on the two end carpets. Lattices drawn for other values of $(f_r\cot z)/q$ revealed the same linearity with k, and lattices drawn in a similar fashion for various constant values of k, varying $(f_r\cot z)/q$, also showed a linear trend over the range $1 \leqslant |(f_r\cot z)/q| \leqslant 5$. Since this range seemed reasonable in view of the experimental results quoted by Kuhn and Griffith[2], it was thought that it should be possible to develop a form of nomogram combining the two types of lattice plot (*i.e.*, k constant and $(f_r\cot z)/q$ constant respectively) and taking account of the linear properties by including only the four end carpets. This was done as shown in Fig. 4. In this diagram the lattices drawn for constant values of $(f_r\cot z)/q$ run diagonally downwards from left to right, while those for constant values of k run diagonally upwards from left to right. The letters on the figure refer to the example discussed in the next section.

METHOD OF USE OF NOMOGRAM

The following example illustrates the use of the nomogram. It is required to determine the value of z corresponding to the following known values of the other parameters: —

$$k=0{\cdot}5;\ \frac{f_s\tan z}{q}=-1;\ \frac{f_r\cot z}{q}=-3{\cdot}5;\ \frac{h}{R}\sqrt{\left(\frac{E}{q}\right)}=2{\cdot}0.$$

The points A, B, C, D are located on the four carpets corresponding to $(f_s\tan z)/q=-1$ and $(h/R)\sqrt{(E/q)}=2{\cdot}0$. Linear interpolation for k along the straight line joining A and B gives the point E, which now corresponds to $(f_s\tan z)/q=-1$, $(h/R)\sqrt{(E/q)}=2{\cdot}0$, $k=0{\cdot}5$, and $(f_r\cot z)/q=-1$. Similarly, the point F is obtained by linear interpolation for k between C and D. Interpolation between E and F for $(f_r\cot z)/q$ gives the point G corresponding to the given values of all the parameters. The point G lies on a carpet whose origin is at 0, given as the intersection on the "base" of the lines corresponding to $k=0{\cdot}5$ and $(f_r\cot z)/q=-3{\cdot}5$. Measuring upwards from 0 to the point G, using the scale indicated for z, the value of z required is obtained as $38{\cdot}5°$. The same value was obtained in this instance by continuous approximation, the latter method requiring a longer time than application of the nomogram.

CONCLUSION

Although the nomogram described permits a rapid determination of z, it must be pointed out that the linearity on which the successful application of the nomogram depends does not hold in the range $0 \leqslant |(f_r\cot z)/q| \leqslant 1$ for small values of $(f_s\tan z)/q$ and $(h/R)\sqrt{(E/q)}$. Similarly for values of $|(f_r\cot z)/q| > 5$ there is a slight departure from linearity, particularly for small values of $(f_s\tan z)/q$ and $(h/R)\sqrt{(E/q)}$.

Apart from this possible defect in so far as complete practical application is concerned, the development of the nomogram described affords an interesting example of the possibilities of carpet and lattice plotting, and it is hoped that greater use will be made of this form of graphical representation in fields other than those in which it is at present in fairly common use.

ACKNOWLEDGMENT

This paper is based on work done by the writer in the course of his duties at Saunders-Roe Limited, and acknowledgment is made by him to the Directors and Chief Designer for permission to publish.

REFERENCES

1. YATES, A. H. (1946). Carpets and Lattices. *Aircraft Engineering*, January 1946.
2. KUHN, P. and GRIFFITH, G. E. (1947). Diagonal Tension in Curved Webs. N.A.C.A. T.N. 1481, 1947.
3. KUHN, P., PETERSON, J. P. and LEVIN, L. R. (1952). A Summary of Diagonal Tension. Part I—Method of Analysis. N.A.C.A. T.N. 2661, 1952.
4. KUHN, P., PETERSON, J. P. and LEVIN, L. R. (1952). A Summary of Diagonal Tension. Part II—Experimental Evidence. N.A.C.A. T.N. 2662, 1952.

The Bending of Some Common Beam Sections into the Plastic Range

by

ANTHONY J. BARRETT, M.S. in A.E., B.Sc.(Eng.), Grad.R.Ae.S.

(Technical Department, Royal Aeronautical Society)

SUMMARY

THERE is already in existence a fair volume of work on the subject of bending beyond the limit of proportionality, most of which requires the use of actual material stress-strain curves. This note aims to examine the problem in a more general way by using an accurate mathematical form for the stress-strain curve, strain and bending moments being expressed as functions of the ratios of various properties of the material.

The value of maximum permissible fibre stress is considered in relation to current requirements for military aircraft stressing and a guide is presented for the maximum permissible bending moment in some of the more familiar beam cross sections bending about an axis of symmetry.

Received January 1953

1. INTRODUCTION

When the cross section of a beam is subjected to a pure bending moment of such magnitude that the stresses in the outer fibres exceed the limit of propor-

tionality for the material, the stress distribution across the beam ceases to be linear and the elementary theory of bending is no longer applicable. In order to relate the bending moment to the maximum fibre stress, under these conditions, it is necessary to evaluate the first moment of the actual stress distribution about the neutral axis. This process is familiar and requires no detailed explanation here, although it may be pertinent to reiterate the assumptions usually made, namely:—

(*i*) the variation of strain across the cross section is linear, that is, sections plane before bending remain plane during bending.

(*ii*) the stress-strain curve is identical in both tension and compression.

(*iii*) the geometry of the beam remains sensibly unaltered during the bending process.

Cases of pure bending about an axis of symmetry for some simple sections will now be considered.

NOTATION

x, y	rectangular co-ordinate system
b, h, t, D, R	dimensions of the cross sections (*see* Figs. 1, 4 and 6)
Z	section modulus
A, B, n	constants in equation (2)
f	stress
f_2, f_5	0·2 per cent. and 0·5 per cent. proof stresses
E	modulus of elasticity
ε	strain
ε_{max}	maximum strain
ε_5	strain corresponding to the 0·5 per cent. proof stress
M	bending moment
K	form factor
Φ	defined by equation (4)

2. RECTANGULAR SECTION IN PURE BENDING

Consideration will now be given to the solid rectangular section, shown in Fig. 1(*a*), subjected to a bending moment, M_{xx}, about the x-axis. The stress distribution across the section is shown in Fig. 1(*b*). Taking moments about the x-axis:—

$$M_{xx}=4b\int_0^{D} fy\,dy$$

If the maximum fibre strain is ε_{max} then, from the first assumption

$$y=\frac{\varepsilon}{\varepsilon_{max}}D$$

giving

$$M_{xx}=\frac{4bD^2}{\varepsilon_{max}^2}\int_0^{\varepsilon_{max}} f\varepsilon\,d\varepsilon . \quad . \quad . \quad (1)$$

The integral is usually evaluated by a process of arithmetical summation applied to an actual stress-strain curve. For the purposes of this note it is desirable to employ the mathematical form:—

$$\varepsilon=A\left(\frac{f}{f_2}\right)+B\left(\frac{f}{f_2}\right)^n \quad . \quad . \quad (2)$$

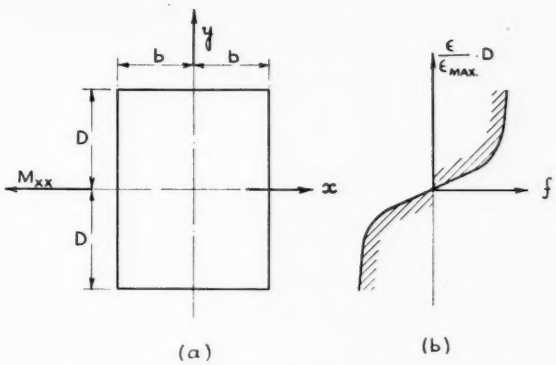


FIGURE 1. Solid rectangular section bending about an axis of symmetry.

Making this curve pass through the 0·2 per cent. and 0·5 per cent. proof stresses and to have the initial value of $df/d\varepsilon=E$ gives a very close approximation to actual stress-strain curves, at least up to the 0·5 per cent. proof stress, for those ductile materials commonly used in aircraft structures.

In this case

$$A=\frac{f_2}{E}, \qquad B=0{\cdot}002,$$

and values of n are as given in Table I.

Substituting expression (2) into (1) gives

$$M_{xx}=\frac{4bD^2}{\varepsilon_{max}^2}\int_0^{f_{max}}\left[A^2\left(\frac{f}{f_2}\right)^2+AB(n+1)\left(\frac{f}{f_2}\right)^{n+1}+nB^2\left(\frac{f}{f_2}\right)^{2n}\right]df=\frac{4bD^2}{\varepsilon_{max}^2}f_2\Phi \quad . \quad (3)$$

where

$$\Phi=\frac{A^2}{3}F_{max}^3+AB\frac{(n+1)}{(n+2)}F_{max}^{n+2}+\frac{nB^2}{(2n+1)}F_{max}^{2n+1} . \quad . \quad . \quad . \quad (4)$$

$F_{max}=f_{max}/f_2$ has been used in equation (4).

By using the mathematical expression for the stress-strain curve it has been possible to relate the bending moment sustained by the rectangular beam to the cross-sectional dimensions, an arbitary stress (in this case f_2), a function derived from the form of the stress-strain curve and the maximum fibre stress and strain.

Before proceeding further it is desirable to give some thought to the form of presentation of these results and to the maximum fibre stress allowable for aircraft "stressing" purposes.

F. P. Cozzone[1] develops a method for determining the bending moment carried by almost any type of symmetrical section and at any value of the maximum fibre stress. By use of the curves which are presented, it is possible to estimate the bending moment for a given

TABLE I

f_5/f_2	1·000	1·025	1·050	1·075	1·100	1·150	1·200
n	∞	37·12	18·78	12·67	9·61	6·56	5·03

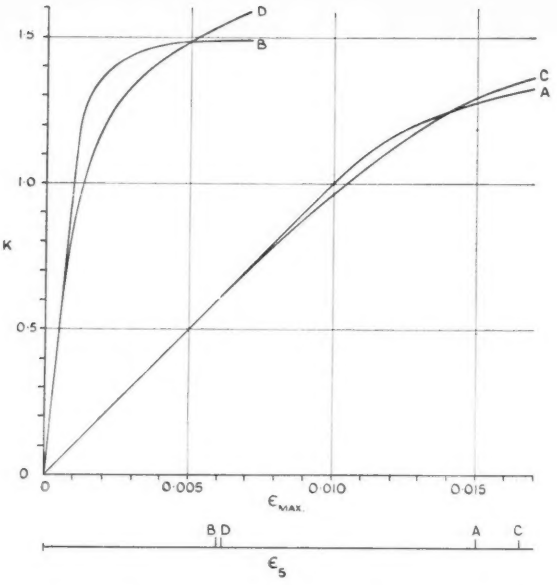


FIGURE 2. Variation of K with the maximum fibre strain in a solid rectangular section.

maximum fibre stress (and *vice versa*) for a large number of beam cross sections. It has become common practice in this country, however, to apply a factor to the expression for elastic bending in order to allow for the non-linearity of the stress-strain curve beyond the limit of proportionality. This factor, known as the Form Factor (*see* Ref. 2) is defined by

$$M_{max}=f'KZ,$$

in which f' is some arbitrarily specified stress (usually the 0·2 per cent. proof stress).

The designation of factor K as a *form* factor is perhaps not a happy one. It is too easy to associate K with the section modulus Z only and thereafter to evaluate stresses from a given applied bending moment for comparison with some maximum permissible stress. For a strictly correct interpretation, K must also be associated with the arbitrary stress f', the maximum fibre stress for which K has been evaluated and the form of the stress-strain curve, as will be seen from expression (6). Thus any given applied bending moment can only be compared with the maximum permissible bending moment evaluated above. In accordance with current practice, permissible bending moments in terms of a form factor are defined by

$$M_{max}=f_2KZ. \quad . \quad . \quad . \quad (5)$$

The maximum fibre stress for which K is evaluated has still not been fixed. In order to help in deciding upon this maximum stress, further consideration will be given to expression (3), written in the form

$$M_{xx}=3f_2\frac{\Phi}{\epsilon_{max}^2}Z$$

and from (5), when M_{xx} is the maximum moment permissible,

$$K=\frac{3\Phi}{\epsilon_{max}^2}. \quad . \quad . \quad . \quad (6)$$

In Fig. 2, K has been plotted against the value of the maximum fibre strain for four forms of the stress-strain curve. These stress-strain curves have the characteristics specified in Table II. Most of the ductile materials used in aircraft work have values of f_5/f_2 and E/f_2 well within the extremes represented by the materials A, B, C and D.

From Fig. 2 it is apparent that after a strain ϵ_5, corresponding to the 0·5 per cent. proof stress, has been reached in the extreme fibres, further straining does not produce a significant increase in K and the bending moment carried by the beam.

The limitation on the maximum permissible fibre strain must also be related to the current military requirement for a proof loading of 75 per cent. of ultimate. Referring again to Fig. 2, taking 75 per cent. of the values of bending moment at ϵ_5 (*i.e.* 75 per cent. of K, since f_2 and Z are constant in equation (5)) gives new values of K which lie on the initial straight line portions of the curves, for A and B, and only slightly beyond this portion for C and D.

Since these initial straight lines represent elastic bending, it is apparent that in general, a maximum fibre strain of ϵ_5 in the ultimate loading condition will satisfy this proof loading requirement.

Re-writing equation (4) with $f_{max}=f_5$ gives

$$\Phi_0=\frac{A^2}{3}F_5^3+AB\frac{(n+1)}{(n+2)}F_5^{n+2}+\frac{B^2n}{(2n+1)}F_5^{2n+1} \quad (7)$$

or, in a form more convenient for the slide rule,

$$\Phi_0=\frac{1}{3}\left(\frac{f_2}{E}\right)^2F_5^3+0{\cdot}005\frac{(n+1)}{(n+2)}\left(\frac{f_2}{E}\right)F_5^2+$$
$$+0{\cdot}005^2\frac{n}{(2n+1)}F_5,$$

where $F_5=f_5/f_2$.

The form factor for a solid rectangular section has been calculated in accordance with expressions (6) and (7) for a wide range of stress-strain curves of the form given in expression (2). The results are shown plotted as the curves of Fig. 3.

The values of f_5/f_2 and E/f_2 for a number of steels and aluminium alloys are plotted on Fig. 3 and it will be seen that the form factor for a rectangular section of the hypothetical material represented by the asterisk lies within 5 per cent. of the form factors for most of these materials. (The horizontal chain-dotted lines include the region for which this observation is true).

TABLE II

Material	f_5/f_2	E/f_2
A	1·00	100
B	1·00	1,000
C	1·15	100
D	1·15	1,000

In view of the assumptions made in the Introduction, particularly (*ii*), it does not seem likely that the value of the bending moment predicted would be correct to within 5 per cent. This leads to the conclusion that the form factors for rectangular section in ductile materials can be represented by the form factor based on some suitably standardised stress-strain curve and there would not seem to be a great deal of merit in presenting form factors for individual materials for most practical "stressing" purposes.

3. I-BEAMS, HOLLOW RECTANGULAR SECTIONS AND CHANNELS BENDING ABOUT AN AXIS OF SYMMETRY

For the sake of completeness, the expression for maximum bending moment in these sections will be derived, although this derivation is by now well known. The same criterion of a maximum fibre stress of 0·5 per cent proof, used in Section 2, will be used again.

Referring to Fig. 4,

$$M_{xx} = 2d\int_0^{h/2} fy\,dy - 2(d-b)\int_0^{h/2-t} fy\,dy$$

$$= \frac{h^2 d}{2\varepsilon_5^{\,2}}\left[\int_0^{\varepsilon_5} f\varepsilon\,d\varepsilon - \left(1-\frac{b}{d}\right)\int_0^{\left(1-\frac{2t}{h}\right)\varepsilon_5} f\varepsilon\,d\varepsilon\right]$$

$$K = \frac{3}{\left[1-\left(1-\frac{b}{d}\right)\left(1-\frac{2t}{h}\right)^3\right] f_2\varepsilon_5^{\,2}}\left[\int_0^{\varepsilon_5} f\varepsilon\,d\varepsilon - \left(1-\frac{b}{d}\right)\int_0^{\left(1-\frac{2t}{h}\right)\varepsilon_5} f\varepsilon\,d\varepsilon\right] \quad . \quad (8)$$

The values of K will be calculated for a standardised form of the stress-strain curve chosen so as to be representative of a large number of common ductile materials. Referring once more to Fig. 3 it will be seen that the abscissae are values of f_5/f_2, and are the values of K for the limiting case of a flanged section with virtually no web and thin flanges. Therefore, the form of the stress-strain curve, as represented by the point marked with an asterisk, gives values of K within 5 per cent. of the actual values of K for the limiting cases of the solid rectangle and the section with point flanges for all materials which fall within the area bounded by the chain-dotted lines. This would justify using this form, except that it is desirable to present conservative values of the form factor for the case of thin flanges, due to the possibility of instability failures therein. The values of K for this limiting case may be reduced by using a standardised curve corresponding to $E/f_2 = 250$ and $f_5/f_2 = 1{\cdot}0$. This is a limiting case of the form of curve represented by equation (2) and consists of two straight lines as shown in Fig. 4(*d*).

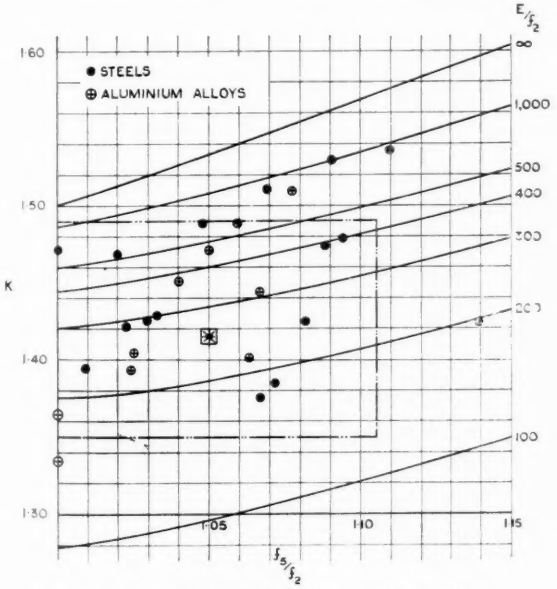


FIGURE 3. Form factors of solid rectangular sections.

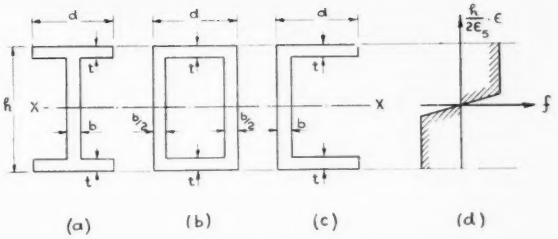


FIGURE 4. Some common sections bending about an axis of symmetry.

It should be emphasised that the choice of this stress-strain curve, although resulting in slightly conservative values for thin walled sections, is no insurance against an instability failure. All thin-walled sections must be checked by use of Ref. 3, for example.

Substituting

$$\frac{f}{f_2} = \frac{E}{f_2}\varepsilon \text{ for } 0 < \varepsilon < 0{\cdot}004$$

and

$$\frac{f}{f_2} = 1 \text{ for } 0{\cdot}004 < \varepsilon < \varepsilon_5$$

in (8) gives

$$\left.\begin{aligned} K &= \frac{3}{\left[1-\left(1-\frac{b}{d}\right)\left(1-\frac{2t}{h}\right)^3\right]}\left[0{\cdot}467 - \right. \\ &\left. -0{\cdot}75\left(1-\frac{b}{d}\right)\left(1-\frac{2t}{h}\right)^3\right] \text{ for } 0{\cdot}5 > \frac{t}{h} > 0{\cdot}278 \\ \text{and} \\ K &= \frac{3}{\left[1-\left(1-\frac{b}{d}\right)\left(1-\frac{2t}{h}\right)^3\right]}\left\{0{\cdot}467 - \right. \\ &\left. -\left[1-\frac{b}{d}\right]\left[0{\cdot}5\left(1-\frac{2t}{h}\right)^2 - \right.\right. \\ &\left.\left. -0{\cdot}033\right\} \text{ for } 0{\cdot}278 > \frac{t}{h} > 0 \end{aligned}\right\} \quad (9)$$

Form factors for flanged sections are calculated from these expressions and are plotted in Fig. 5. It is suggested that they may be used as a guide for sections in most of the ductile materials at present in use.

4. CIRCULAR SECTION IN PURE BENDING

A hollow circular section, as shown in Fig. 6(*a*), is assumed to have the stress distribution shown in Fig. 6(*b*) under the action of pure bending about the *x*-axis.

$$M_{xx}=4\int_0^R f(R^2-y^2)^{\frac{1}{2}}y\,dy-4\int_0^{R-t} f[(R-t)^2-y^2]^{\frac{1}{2}}y\,dy\,.$$

With

$$\varepsilon=\frac{y}{R}\varepsilon_5 \quad \text{and} \quad K=\frac{4M_{xx}}{\pi R^3\left[1-\left(1-\frac{t}{R}\right)^4\right]}$$

$$K=\frac{16}{\pi\left[1-\left(1-\frac{t}{R}\right)^4\right]f_2\varepsilon_5^3}\left\{\int_0^{\varepsilon_5} f(\varepsilon_5^2-\varepsilon^2)^{\frac{1}{2}}\varepsilon\,d\varepsilon-\int_0^{\left(1-\frac{t}{R}\right)\varepsilon_5} f\left[\left(1-\frac{t}{R}\right)^2\varepsilon_5^2-\varepsilon^2\right]^{\frac{1}{2}}\varepsilon\,d\varepsilon\right\}.$$

Using the same standardised stress-strain curve employed in Section 3

$$\left.\begin{aligned}&\frac{\pi\left[1-\left(1-\frac{t}{R}\right)^4\right]}{16}K=0{\cdot}301-\left(1-\frac{t}{R}\right)^3\\&\left\{\frac{1}{3}\cos^3\theta+\left[\frac{4}{81}\frac{1}{\left(1-\frac{t}{R}\right)^2}-\frac{1}{8}\right]\cos\theta+\frac{9}{32}\left(1-\frac{t}{R}\right)\theta\right\}\end{aligned}\right\}\quad(10)$$

where $\theta=\sin^{-1}\dfrac{4}{9}\dfrac{1}{\left(1-\frac{t}{R}\right)}$ for $0<\dfrac{t}{R}<\dfrac{5}{9}$

and $\theta=\dfrac{\pi}{2}$ for $\dfrac{5}{9}<\dfrac{t}{R}<1{\cdot}0$.

These values have been plotted in Fig. 7, and it is suggested that they may be used as a guide for circular sections in most of the ductile materials at present in use.

For thin tubes, a check should be made for instability failure which may occur before the 0·5 per cent. proof stress has been reached in the extreme fibres. Since it is not the purpose of this note to discuss this aspect of bending, the values of equation (9) below $t/R=0{\cdot}3$ have been omitted from Fig. 7. The broken line indicates the probable trend of K for thin tubes in this region and, in form, is in agreement with the recommendations of Ref. 4, which are based upon experimental evidence.

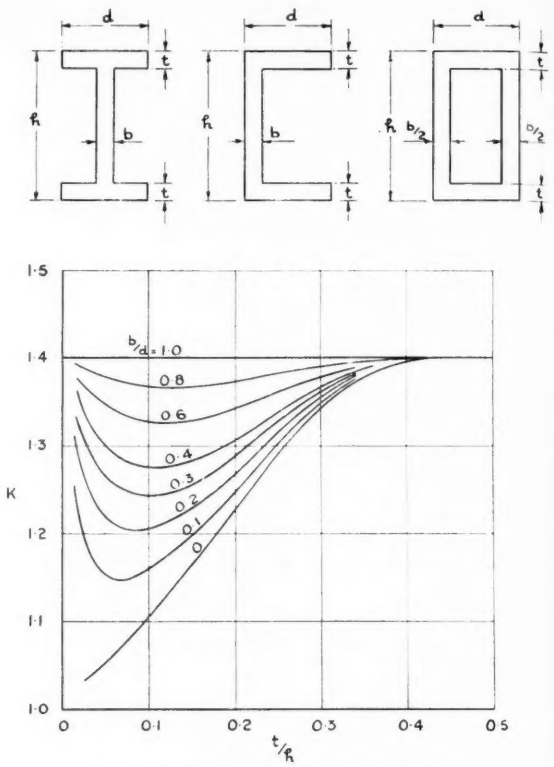


FIGURE 5. Some factors for flanged sections.

5. CONCLUSION

The permissible bending moment obtained from a form factor based on a standardised form of the stress-strain curve and working to a maximum fibre stress of the 0·5 per cent. proof stress would seem to be quite suitable for most aircraft "stressing" purposes when dealing with the type of cross section considered in this note. These form factors are to within some 5 per cent. of form factors based upon actual stress-strain curves for most ductile materials, the same assumptions being made in both cases.

With reference to one of these assumptions, the reader should note that it is quite possible to take into account the difference in compression and tension stress-

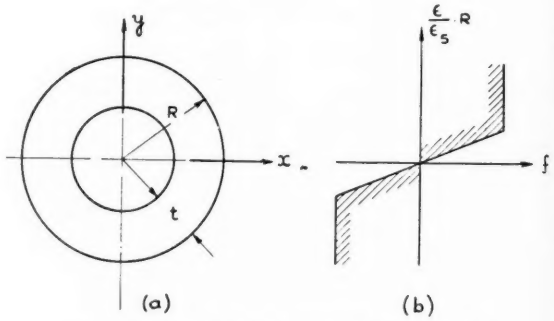


FIGURE 6. Hollow circular section in pure bending.

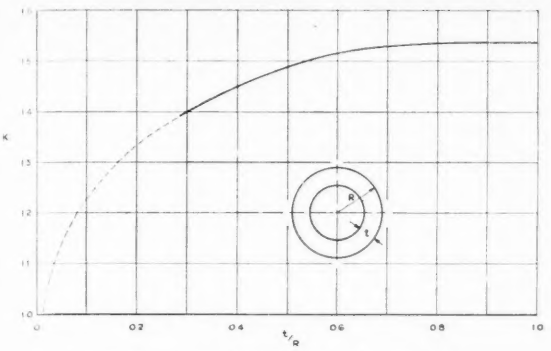


FIGURE 7. Form factors for circular sections.

strain curves and the consequent movement of the neutral axis, although information on the compression stress-strain curves is not in such common use as that for tension. The results of such an analysis would be somewhat bulky as a separate family of curves would be necessary for each material and type of section.

The use of the 0·5 per cent. proof stress as a limiting value has been shown to be governed by the necessity of satisfying current military requirements and by the fact that a higher stress is not justified by any large increase in bending moment. There is a further point that in certain applications it is desirable to limit the deflections of the beam.

This note has confined attention to pure bending about an axis of symmetry. There is at present little published information on the problems of pure bending about other axes or bending combined with axial loading, which is in a form suitable for application to aircraft stressing. An analysis has been completed which will be published in a later Technical Note, giving some consideration to these problems.

ACKNOWLEDGMENT

The author wishes to acknowledge the general assistance rendered by Mr. D. C. Smith, Head of the Technical Department, in the preparation of this note and that many of the points made herein originated from various members of the Society's Structures Committee during their deliberations on problems involving bending beyond the limit of proportionality.

REFERENCES

1. COZZONE, F. P. (1943). Bending Strength in the Plastic Range. *Journal of the Aeronautical Sciences*, May 1943.
2. BEILSCHMIDT, J. L. (1942). The Stresses Developed in Sections Subjected to Bending Moment. *Journal of the Royal Aeronautical Society*, July 1942.
3. Royal Aeronautical Society's Structures Data Sheets. 01.01.08, Local Instability of Aluminium Alloy Struts with Flat Sides, and 01.01.09, Local Instability Stress Coefficients for Channel and Z-Section Struts.
4. Aircraft Committee of the United States Munitions Board. Strength of Metal Aircraft Elements, Bulletin ANC-5, revised edition June 1951.

THE LIBRARY

Reviews

ADVANCED STRENGTH OF MATERIALS. *J. P. Den Hartog. McGraw-Hill 1952. 379 pp. Diagrams. 72s. 6d. net.*

Engineers appear to be condemned throughout eternity to having what they recognise as "Applied Elasticity" described as "Strength of Materials." Call it what you will, several good books have been published in recent years on the subject of stress and strain distribution in solids and it might almost be said that for a new book to be necessary it must either contain new material or present a fresh approach to the subject.

Professor Den Hartog has produced a most interesting and stimulating book. As he says, his object was to bridge the gap between elementary strength of materials and advanced books on theory of elasticity.

This is not a book for the novice, but part of it could be read in this country by a final year honours engineering student and the rest by a first year research worker. Inevitably most of the subject matter of the book has been covered by existing books but in many cases a new approach to the problem has been made. The first, and one of the largest chapters in the book is devoted to torsion, which is very adequately treated, including an excellent description of Kelvin's fluid flow analogy, which is generally not so well known among students as Prandtl's membrane analogy. Rotating discs, including discs of variable thickness, are well treated. The chapter on membrane stresses in shells left the reviewer feeling, as it were, a little hungry and wishing that a more general approach to the problem could have been made in which an introduction to bending stresses in shells might have been given. The bending of flat plates is most clearly and refreshingly described and a useful catalogue of results is included. A chapter is devoted to beams on elastic foundations and forms a good introduction to this subject. There is a chapter on the two-dimensional theory of elasticity in which the Airy stress function is well and honestly described, inasmuch as it is made clear to the reader that in many cases a stress function is assumed and the problem to which it is applicable is then derived, an approach which is not always clearly described and baffles many engineering students. A few pages at the end of this chapter are somewhat inadequately devoted to plasticity.

A chapter on the energy method describes and differentiates between the theories of virtual work, Castigliano and least work. This exposition is most interesting and readable.

The longest chapter in the book is concerned with buckling, and serves as an excellent introduction to this subject and, among other things, contains a very clear account of Vianello's method.

The last chapter deals with miscellaneous topics and the book concludes with 217 interesting and well selected problems, to which answers are given.

The book is written in a straightforward, robust style and is copiously illustrated with excellent sketches. The production of the book is in accordance with the high reputation of the publishers.—S. C. REDSHAW.

ACROSS THE SPACE FRONTIER. *Edited by Cornelius Ryan. Sidgwick & Jackson, London, 1952. 147 pp. 12 colour plates, photographs and diagrams. 21s. net.*

This fascinating and beautifully produced book is an expansion of a feature article which appeared early in 1952 in the American "Collier's Magazine." Like its original source, it is the work of a panel of experts, and tells how a number of huge liquid-propellant rocket ships might be employed to establish a station in space, which in turn might be used as a starting point, and refuelling base, for interplanetary voyages.

All the authors make interesting contributions; after a brief introduction by the editor, Dr. Kaplan (a professor of physics at the University of California) describes the Earth's atmosphere, particularly with regard to its upper levels. Other contributions are from Dr. Haber (on the physiological aspects of space flight), Willy Ley (on conditions in the space station), and the well-known American astronomer, Dr. Whipple, who discusses the benefits which astronomers would gain from the ability to fly beyond the atmosphere. A chapter ("Who Owns the Universe?") is written by the deputy director of the UNO legal department (Oscar Schachter) and deals with the problems of international law which will arise in the future world of space ships and space stations! Excellent colour plates are provided by Chesley Bonestell, Rolf Klep and Fred Freeman.

However, by far the longest and most important section is by Dr. Wernher von Braun, who was technically responsible for the V.2 and several other German wartime rocket projects, and who is now Technical Director of the U.S. Army Guided Missile Development Group at Redstone Arsenal, Alabama. This deals fully with the engineering and scientific problems of the rocket vehicles concerned; while the statement on the dust jacket, to the effect that the book is "an accurate blue-print," can be rejected, it nevertheless does present a well-documented argument, more detailed than the original magazine article on which it is based.

Von Braun is a most ardent devotee of the cause of interplanetary flight, enthusiastic, optimistic, and impatient. Many readers, including this reviewer, will agree with the opinion of Sir Harold Spencer Jones, the Astronomer Royal, who contributes a Foreward to the British edition. He writes: "The enthusiasts say that it could be done in ten years; but the problems to be investigated and to be solved are so many and so varied that I am inclined to give a much more cautious estimate and to say that half a century would not be an unduly long time." Very probably, the achievement of interplanetary flight will take longer than von Braun hopes, and in the end will result from the application of new discoveries and inventions, only dimly-conceived to-day, rather than from the mere extrapolation of present practices in rocket design, as advocated by him. One is also a little sceptical (not to say suspicious) of his energetic attempts to "sell" space ships, and the space station, as worthwhile military projects,

capable of launching atomic bombs on the poor old Earth with little fear of reprisal.

In fairness, it should be explained that these are not the real reasons why von Braun wants to fly beyond the atmosphere. Rather, to quote the Astronomer Royal once more, he is one of " those who are prepared to accept the challenge "—of the conquest of space—and: " This book shows that their faith is not mere idle fancy but that there are solid grounds for believing that sooner or later success will be theirs."—A. V. CLEAVER.

HANDBOOK OF SUPERSONIC AERODYNAMICS. *Navord Report 1488. Vols. 1, 2 and 4. Compiled and edited at the Johns Hopkins University. Published by the Bureau of Ordnance, U.S. Government Printing Office, Washington. $4.50 net.*

It must be emphasised at the outset that this handbook is still far from complete. The present volumes contain chapters on notation, on the basic equations of supersonic flow, on one-dimensional flow, and on aeroelastic effects, tables of atmospheric data, and tables of various isentropic flow and shock-wave relationships. Chapters on two- and three-dimensional wings, on bodies, on ducts and diffusers, on supersonic tunnels, and on stability have yet to be written, and secrecy shrouds the volume on viscosity effects. It is therefore impossible to make a comprehensive judgment of this work at the present time; we can only judge the existing chapters on their individual merits.

The chapter entitled " Fundamental Equations and Formulæ " deals with the basic differential equations of compressible fluid flow and then proceeds to the well-known formulæ of isentropic flow, Prandtl-Meyer flow and oblique-shock flow. This chapter is not altogether satisfactory: the final equations are, in the main, presented in a more comprehensive and orderly fashion in N.A.C.A. T.N. 1428, " Notes and Tables for Use in the Analyses of Supersonic Flow," and while derivations of many of the basic equations are included in the present work they are of limited value, because other equally important relations are simply quoted. Two particular points may be mentioned: one of the hodograph equations is given wrongly (twice), and no mention is made of the connection between isentropy and irrotationality.

The chapter on one-dimensional flow, which is a verbatim reproduction of a paper by Shapiro and Edelman, deals in a thorough and systematic fashion with the flow in a tube subject to area change, fuel addition, shocks, friction, and heat exchange. These effects are discussed one at a time and it is shown how the various results may be combined. The usual assumptions of one-dimensional treatments are made: for example it is assumed that the skin friction coefficient is constant along a pipe and that friction losses are distributed instantaneously across each section normal to the flow. The presentation in tabular form of algebraic expressions for the " influence coefficients," which determine the effect on Mach number of the various changes above, is helpful; and the accompanying numerical tables, which give values of these coefficients and of various other relevant functions of Mach numbers for a wide range of specific heat ratio, should prove useful.

The section entitled " Aeroelastic Phenomena at Supersonic Speeds " deals only with flutter. There is a short introduction giving the basic concepts of flutter theory, followed by a brief treatment of certain theoretical aspects of flutter at supersonic speeds. Single-degree-of-freedom torsional flutter is considered in some detail, and stability boundaries are given showing the critical conditions for undamped oscillations. The equations of two-dimensional and three-dimensional binary flexure torsion flutter are developed, using the method of semi-rigid representation, and two examples of binary flutter are given (flexure-flexure-torsion and flexure-torsion-aileron flutter). The section ends with two comprehensive sets of tables, giving the reduced frequency parameter and the values of the flutter derivatives in terms of the Mach number and the frequency parameter. The details given of the flutter analysis are well known to the specialist, but are far too brief to be comprehended by a newcomer to the subject. The derivation of the aerodynamic derivatives is not discussed, and only one method of solving the flutter determinant is given.

Since Americans use a standard atmosphere different from our own, those designers in this country who still manage to restrict their activities to altitudes of less than 70,000 feet will have only a limited interest in the considerable atmospheric data given in this book; their more ambitious colleagues, however, will doubtless welcome data, no matter how speculative, which extends to a height of 40,000 miles.

The extensive supersonic flow tables give the values of a large number of important ratios, such as static/total pressure in isentropic flow and the pressure ratio across a normal shock, as functions of Mach number. The Mach number range is 0 to 5·00, at intervals of 0·01, and entries are in general given to five significant figures. These tables are on the whole of a high standard; the oblique-shock tables are particularly welcome in that the intervals of both the independent variables (upstream Mach number and flow deflection) are small, so that linear interpolation is sufficient almost everywhere. However, the tables of Prandtl-Meyer angle, which are important for calculations by the method of characteristics, are inferior to those of Herbert and Older.

If the function of a handbook is to select carefully the most important results of a subject, and to present them in an orderly and wholly convenient form, this work, judged on its present contents, cannot be called an unqualified success; however, it contains much that is useful, and the editors' task is certainly not an easy one at this early stage in the development of supersonic aerodynamics.—L. E. FRAENKEL, A. W. BABISTER, The University, Glasgow.

STUDIES IN ELASTIC STRUCTURES. *A. J. S. Pippard. Edward Arnold, London 1952. 361 pp. Diagrams and tables. 60s. net.*

Professor Pippard's book contains a collection of studies of elastic structures which he and his colleagues have made over a number of years. Most of the work described in these studies has been previously published, but in the present book the work has largely been rearranged and expanded.

The great interest and attraction of this work is the insight it gives of the discipline of mind practised by the author in his research work. The problems have first been approached theoretically and then a model, representing the theoretical concept, has been constructed and tested to verify the theory; the models may thus be regarded as mechanical analogues of the theoretical problems. The studies are not merely of academic interest but were all instigated by the spur of practice.

The twelve chapters describe the stresses in circular rings, wheels, braced rings, rotating wheels, interconnected bridge girders, multiple lattice frames, cable bracing, restrained pipe lines and a braced tube. The analysis of

open panel structures, the bow girder and transversely loaded frames are also included. A chapter is devoted each to the elastic arch rib and the masonry arch.

It is interesting to note that, although the author exploits the principle of superposition most effectively in his treatment of rings and ribs, he does not use the device of the elastic centre which is so popular nowadays for avoiding the solution of the simultaneous questions which arise in problems of this nature. The approach to the problem of the stresses in interconnected bridge girders appears to the reviewer to be a little unwieldy, and many analysts would undoubtedly prefer to attack a problem of this nature by relaxation methods.

The book is written in a most lucid style and should be valuable, not only to those interested in problems of the type described, but in particular to research workers in applied elasticity who should read this book if only for the fine training in research methods which it gives. The book is excellently printed and the diagrams have been very clearly drawn and produced.—S. C. REDSHAW.

ELEMENTS OF WAVE MECHANICS. *N. F. Mott. Cambridge University Press 1952. 156 pp. 30 figures. 21s. net.*

This latest book of Professor Mott is designed to replace his previous work, "An Outline of Wave Mechanics," published in 1930. The author states that "Elements of Wave Mechanics" is intended for students in the final year of an honours course of experimental physics and also, as an introduction to more advanced textbooks, for those who intend to specialise in the subject. It is interesting to recall that the earlier book was regarded at the time of publication as of great value to a student who had completed his honours degree in physics and wished to understand the principles of wave mechanics—we can only guess what limits of knowledge will be imposed upon the physics undergraduate twenty years hence! The length of the present book has been kept to the size of its predecessor, despite a widened field of survey, by omission of some mathematical developments easily found in other textbooks.

Professor Mott sets out to build up his elementary theory from experimental facts, for example, the relation $\lambda = h/p$ connecting the wave-length and momentum of an electron, he regards as established from electron diffraction experiments although historically it had been predicted previously by de Broglie. Subsequently the author shows how simple problems may be solved, but wisely leaves some examples for the student reader himself to tackle; no effort is made to introduce philosophy or metaphysics into the book. The subject matter includes a summary of a few of the more important contributions made by wave mechanics to the theory of solids, and the concluding chapter is devoted to relativistic and nuclear developments. The author has most certainly succeeded in covering the objectives set out in his preface.

The book is well produced and reasonably priced, that is by modern standards, for its predecessor of similar size cost sixty per cent. less.—R. W. B. STEPHENS (Imperial College).

CLIMATE AND THE BRITISH SCENE. *Gordon Manley. Collins, London 1952. 314 pp. Photographs, diagrams. 25s. net.*

Professor Manley describes our climate as the most erratic in the world. While we do not, perhaps, appreciate this, we all are profoundly influenced by the diversity in the British scene which is the direct product of the diversity in our climate. The possibility that the national character, as the author suggests, is very much a product of our climate is an interesting subject for speculation.

The main subject of the book is the weather which makes the climate. This is treated in a masterly fashion, particularly when it comes to the discussion of the effect of topography on the weather locally. The subject, obviously, would be incomprehensible without a full discussion of the stability of the atmosphere, the properties of saturated air, and such like matters. This is done in a simple and lucid manner. An important omission, however, is a key to the symbols in the many weather maps which illustrate the text.

While the engineer would like to know the source of the enormous energy in depressions—whether it is simply the steam cycle on a gigantic scale in which we happen for a time to live in the condenser—the author does answer a great many of the questions which come to us all as we move about the country. Where the answer is not complete, the excellent short bibliography to each chapter allows the matter to be pursued further.

Mention must be made of the collection of pictures both coloured and monochrome. These are of exceptional beauty and quality.

This is a book for one's own library.—J. K. HARDY.

OBSERVER'S HANDBOOK. *Meteorological Office. Her Majesty's Stationery Office, London 1952. 216 pp. Diagrams and photographs. 12s. 6d. net.*

Routine observation, at the best, is an uninspiring business. The publication of a guide book for meteorological observers, therefore, is an opportunity to give stimulus and interest as well as information—a few words about the significance of this and that, with references to encourage further reading. The pure routine can be dealt with in a concise and businesslike manner. Abnormalities can be treated fully and positively since there is vast experience on which to draw. The observer should not be given the feeling that the interpretation of the data he provides is quite beyond him.

The Handbook is not up fully to these requirements. There is much that is straightforward and to the point, but there is much that is vague and unsatisfactory. The definitions in Chapter 4 are an example. Does it help to be told that "Rain is liquid precipitation in the form of drops of appreciable size thereby differing from drizzle"? Size should be stated and rate of fall of drop given, as well as any other information which may be of help in determining size. There is the same absence of clear thought in nearly all the other definitions—a serious defect.

The whole question of the effect of obstructions on the measurements of wind strength and direction could, one feels, be dealt with in the same positive fashion as is the siting of the sunshine recorder. Where there are obstructions it seems possible to make corrections based on measurements made with a temporary mast placed in the free wind near the site. At a station where there are no measuring instruments and the observer estimates wind velocity from the feel of the wind, it seems that measurements with a simple swinging vane would be an improvement.

The reproduction of the cloud photographs is poor. It is worth making a good job of these, if necessary omitting other illustrations, several of which can be eliminated without serious loss.

The Handbook would be the better for a thorough and, in places, ruthless working over by the editor.—J. K. HARDY.

THE PHYSICAL ASPECTS OF AIR PHOTOGRAPHY. *G. C. Brock, M.Sc., F.R.P.S. Longmans Green. 1952. 267 pp. Diagrams and photographs. 56s. net.*

Map making and photographic interpretation both require, in the negative and positive photograph, that there be the maximum definition possible. This book, by an acknowledged expert, gives a very thorough treatment of the modern techniques used in air photography. The author has wisely omitted from the book many purely photographic matters which can be found in textbooks of photography, yet he has managed to include sufficient of the basic principles to render the volume clear and concise even to those not actively engaged in the development of the latent image. Here indeed, if we read and note, we have the opportunity of improving the standard of air photography even though we may only administer, specify, or fly, the photographic sortie. A void that has for so long been present in the bibliography of those engaged in reconnaissance flying, surveying, and intelligence has at last been filled.

By concerning himself principally with the physical aspects of air photography the author keeps the reader always aware of the characteristics and limitations of photographic materials, factors which when neglected frequently lead to those unsatisfactory photographs which fall below the highest standard that the correct technique will give.

From the air, the estimation of negative exposure is difficult even to the experienced photographer. Mr. Brock strongly advocates the use of photometric measurement of the subject brightness, allied with intelligent observation of the prevailing factors. Thus he deals at some length with the effect of atmospheric haze and absorption, the variations of the spectral quality of daylight, the effect of aircraft height, and the nature of the terrain.

Two chapters deal briefly with such media as colour photography and infra-red photography. Here the viewpoint held is that their use is only justified if they convey information not given by normal orthochromatic or panchromatic film. To illustrate this, comparative photographs are given in twelve of the many plates which illustrate the text.

Constantly we are reminded that the object of air photography is to obtain the very best image sharpness and the very highest possible resolution of ground detail. There has long been a need for information whereby these goals may be achieved; if the author succeeds in obtaining even some improvement in the standard his efforts will not have been in vain. Anyone engaged in aerial photographic work should read this book—by so doing he can help his fellows in the profession.—E. A. MISKIN.

Additions to the Library

American Society of Mechanical Engineers. SHOCK VIBRATION INSTRUMENTATION. 1952.

*American Society for Testing Materials. FIFTY-YEAR INDEX TO A.S.T.M. TECHNICAL PAPERS AND REPORTS, 1898-1950. 1952.

Anglo-American Council on Productivity. ZINC AND ALUMINIUM DIE CASTING. 1952.

Bosworth, R. C. L. HEAT TRANSFER PHENOMENA. Pergamon Press. 1952.

Burge, C. G. (*General Editor*). HANDBOOK OF AERONAUTICS, Vol. 1. STRUCTURAL PRINCIPLES AND DATA. Pitman. 1952. (*4th edition.*)

De Haven, H. and A. H. Hasbrook. SHOULDER HARNESS: ITS USE AND EFFECTIVENESS. Crash Injury Research. 1952.

Department of Scientific and Industrial Research. MECHANICAL ENGINEERING RESEARCH, 1951. H.M.S.O. 1952.

Department of Scientific and Industrial Research. CERAMICS AND GLASS. Selected Government Research Reports, Vol. 10. H.M.S.O. 1952.

Draper, C. S., W. McKay and S. Lees. INSTRUMENT ENGINEERING, Vol. 1. METHODS FOR DESCRIBING THE SITUATIONS OF INSTRUMENT ENGINEERING. McGraw-Hill. 1952.

Ensrud, A. F. THE ELASTIC POLE. Lockheed Aircraft Corporation. 1952.

Fuchs, E. and H. Bradley (*Editors*). WELDING PRACTICE, Vol. 2. WELDING OF FERROUS METALS. Butterworth. 1952.

Ginoux, J. J. DYNAMIQUE DES FLUIDES COMPRESSIBLES. C.N.E.R.A. 1951.

Good, W. T. THE FIRE RISKS OF AIRCRAFT FACTORIES. Chartered Insurance Institution. 1952.

Grant, E. L. STATISTICAL QUALITY CONTROL. McGraw-Hill. 1952.

Hartog, J. P. den. ADVANCED STRENGTH OF MATERIALS. McGraw-Hill. 1952.

Insull, T. TRANSPORT BY AIR. John Murray. 1952.

Jaworski, A. *Trans-Canada Airlines' Progress* 1946-50—*A Comparison with U.S. Trunk Lines.* Journal of Air Law and Commerce. 1952.

Keith-Lucas, D. THE SHAPE OF WINGS TO COME. B.A. Reprint. 1952.

Lavoisier, G. MOTEURS A REACTION. Technique et Vulgarisation. 1952.

*Mahlmann, C. V. and W. M. Murray (*Editors*). PROCEEDINGS OF THE SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS, Vol. 10, No. 1. 1952.

*Minton, A. S. and E. S. Calvert (*Editors*). DICTIONARY OF FIRE TECHNOLOGY. The Institution of Fire Engineers. 1952.

Murray, W. M. (*Editor*). FATIGUE AND FRACTURE OF METALS—A SYMPOSIUM. Chapman & Hall. 1952.

Nelson, J. R. WRITING THE TECHNICAL REPORT. McGraw-Hill. 1952. (*3rd edition.*)

Ohio State University. PROCEEDINGS OF THE SECOND MIDWESTERN CONFERENCE ON FLUID MECHANICS. 1952.

Ricardo, Sir H. R. THE HIGH-SPEED INTERNAL-COMBUSTION ENGINE. Blackie. 1953. (*4th edition.*)

Shanley, F. R. WEIGHT-STRENGTH ANALYSIS OF AIRCRAFT STRUCTURES. McGraw-Hill. 1952.

Shell-Mex and B.P. Ltd. THE LUBRICATION OF OIL ENGINES. 1952.

Shortal, J. A. N.A.C.A.'s ROLE IN GUIDED MISSILE RESEARCH. (*Reprint.*) Society of Automotive Engineers. 1952.

Smith, M. L. and K. W. STINSON. Fuels and Combustion. McGraw-Hill. 1952.

Stemmer, J. RAKETENANTRIEBE. Schweizer Druck-und-Verlagshaus. 1952.

Tangye, N. and D. H. MacBeath. TEACH YOURSELF TO FLY. E.U.P. 1952.

Ward Lock & Co. THE WONDER BOOK OF AIRCRAFT. 1952.

Westergaard, H. M. THEORY OF ELASTICITY AND PLASTICITY. Chapman & Hall. 1952.

Westinghouse Engineers. ALTERNATING-CURRENT ELECTRICAL SYSTEMS FOR AIRCRAFT. Westinghouse Electric Corporation Aircraft Department. 1951. (*2nd edition.*)

** Items marked with an asterisk may not be taken out on loan. Titles of pamphlets are printed in italics.*

Reports

Summaries of Reports added to the Library

AERODYNAMICS

Boundary Layer

On the flow past a flat plate with uniform suction. B. Thwaites R. & M. 2481.

A new method of performing boundary-layer calculations is introduced in this paper, and is applied to the problem of finding the characteristics of uniform flow past a flat plate through which there is a constant normal velocity. An exact solution to this problem has not yet been found and it is therefore difficult to assess the accuracy of the results obtained. The results, however, are compared with those of two other methods. When the momentum equation is being used, one obvious advantage of the method is that, in "adding" velocity profiles, the momentum thickness of each may be added to give the momentum thickness of the whole. This is not so in the usual methods of boundary-layer calculations, and great simplification is thereby obtained.—(1.1).

Direct measurements of skin friction. S. Dhawan. N.A.C.A. Technical Note 2567.

A device was developed to measure local skin friction on a flat plate by measuring the force exerted on a very small movable part of the flat plate. The apparatus was applied to measurements in the low-speed range, for both laminar and turbulent boundary layers, and the measured skin-friction coefficients show excellent agreement with Blasius' and Von Kármán's results. Measurements were made in high-speed subsonic flow and turbulent-skin-friction coefficients were determined up to a Mach number of about 0·8. A few measurements were also made in supersonic flow.—(1.1).

Investigation of laminar boundary layer in compressible fluids using the Crocco method. E. R. Van Driest. N.A.C.A. Technical Note 2597.

The Crocco method has been used to compute the skin-friction and heat-transfer coefficients for high-speed air flow in the laminar boundary layer on a flat plate, assuming a Prandtl number of 0·75 and constant specific heat, and using the Sutherland viscosity law. Variation of shear, velocity, temperature, and Mach number across the layer are shown. The application of the Crocco method of laminar-boundary-layer analysis is discussed in detail.—(1.1).

Experimental study of the effects of finite surface disturbances and angle of attack on the laminar boundary layer of an N.A.C.A. 64A010 airfoil with area suction. M. A. Schwartzberg and A. L. Braslow. N.A.C.A. Technical Note 2796.

A Langley low-turbulence wind-tunnel investigation of a porous N.A.C.A. 64A010 aerofoil section has been made to determine the effectiveness of area suction in maintaining full-chord laminar flow behind finite disturbances and at angles of attack other than 0°. Area suction resulted in only a small increase in the size of a finite disturbance required to cause premature boundary-layer transition as compared with that for the aerofoil without suction. Combined wake and suction drags lower than the drag of the plain aerofoil were obtained through a range of low lift coefficient by the use of area suction.—(1.1).

Second approximation to laminar compressible boundary layer on flat plate in slip flow. S. H. Maslen. N.A.C.A. Technical Note 2818.

The first-order solution for the laminar compressible boundary-layer flow over a flat plate at constant wall temperature is given. The effect of slip at the wall as well as the interaction between boundary-layer flow and the outer stream flow is taken into consideration. The solution is obtained explicitly in terms of the known zero order, or continuum, solution. No assumptions regarding the Prandtl number or viscosity-temperature law need be made.—(1.1).

Transition and drag measurements on the Boulton Paul sample of laminar-flow wing construction. Part I—J. H. Preston and N. Gregory. Part II—K. W. Kimber. Part III—Joint Discussion. R. & M. 2499.

Transition tests and drag measurements have been carried out on the Boulton Paul sample of laminar-flow wing construction up to $R = 9 \times 10^6$ in the National Physical Laboratory 13×9 ft. tunnel and in the Royal Aircraft Establishment $11\frac{1}{2} \times 8\frac{1}{2}$ ft. tunnel up to $R = 15 \times 10^6$. The minimum drags as measured in the two tunnels are in good agreement with each other, and also with theoretical predictions using the measured transition points over a range of Reynolds number of 2·5 to 15 millions. A tunnel-flight comparison on a wing of this thickness designed for a moderate amount of laminar flow would be very valuable. If, as the present results in the R.A.E. tunnel suggest, some relaxation of the waviness requirements may be possible on such wings, then there is hope of present standards of construction attaining laminar flow on such section without resort to filling. Transition phenomena need to be studied further in relation to waviness, and more attention needs to be paid to the form and number of waves in addition to the amplitude when considering means of reducing the curvature gauge readings.—(1.1 × 1.10).

Compressible Flow

See also Wings and Aerofoils

*The effect of planform on the lift of drag ratio of wing-body combinations at supersonic speeds. B. Beane. Douglas Report SM-*14454.

This report considers the effect of wing-body interference on the lift-drag ratios of certain wing plan forms attached at zero incidence to a cylindrical fuselage. Computations, based on a simplified theory of Lagerstrom and Van Dyke, have been made for a circular body in combination with rectangular and triangular wings, and for an elliptic body combined with delta wings. The underlying assumptions are those of linearised, supersonic thin aerofoil theory.—(1.2).

Fluid Dynamics

Behavior of vortex system behind cruciform wings—motions of fully rolled-up vortices. A. H. Sacks. N.A.C.A. Technical Note 2605.

The motions of four fully rolled-up vortices representing the vortex system trailing behind cruciform wings (banked 45°) at all Mach numbers are investigated by theoretical and visual-flow methods. Equations are developed for the vortex paths in three dimensions, and the distance behind the wing at which the upper two vortices "leapfrog" through the lower two is calculated. Results of some water-tank tests are given and comparisons made with the theory.—(1.4).

Internal Flow

*Tests on four aerofoil cascades. Part I: Deflection, drag and velocity distribution. F. G. Blight and W. Howard. A.R.L. Australia Report E.*74.

The performances of a standard circular arc camber line cascade designed by the method described by M. J. Lighthill in R. & M. 2104 have been determined experimentally in a low speed cascade tunnel. The velocity distribution, air deflection, profile drag and pressure rise through the cascade were measured over a range of air inlet angles and the results have been presented graphically.—(1.5).

*The pumping characteristics of long mixing section jet pumps. N. L. Fox. Douglas Report SM-*14385.

Two theoretical analyses are presented for the pumping characteristics of a jet pump, both of which assume complete mixing in a constant area mixing section which is not choked, and neglected friction. The first analysis, which neglects compressibility, yields an equation sufficiently simple for engineering use. The second analysis, which considers compressibility, leads to a better understanding of the system, but is tedious for calculation. Correction factors,

NOTE:—*The figures in parentheses at the end of each Summary are for office use only.*

based on experimental data and supported by the compressible analysis, are applied to the incompressible analysis to yield results sufficiently accurate for most engineering use.—(1.5).

LOADS

A drag reduction method for wings of fixed planform. E. W. Graham. Douglas Report SM-14441.

A method is given for reducing the drag of wings of fixed plan form, while maintaining constant some property such as wing lift or wing volume. This drag reduction is accomplished through adjustment of the thickness distribution if the volume is fixed. For example, the drag due to lift of flat rectangular wings and flat delta wings is studied.—(1.6).

STABILITY AND CONTROL

See also WINGS AND AEROFOILS

Investigations on stalling behaviour, rudder oscillations, take-off swing and flow round nacelles on the Tudor I aircraft. D. J. Lyons. R. & M. 2789.

During the development of the Tudor I aircraft, the Royal Aircraft Establishment co-operated in the flight tests. This report summarises the results, which are felt to be of general interest. The importance of "deep tufting" in leading to an understanding of varied aerodynamic problems has again been forcibly demonstrated.—(1.8).

Wind-tunnel measurements of yawing moment due to yawing (n_r) on a 1/5·5 scale model of the Meteor Mark F.III. J. G. Ross and R. C. Lock. R. & M. 2791.

During recent investigations into the self-excited oscillations in yaw, experienced on Meteor aircraft, the lateral stability derivative, n_r, was measured in flight, and found to differ considerably during initial experiments from the theoretical estimate. A new technique was therefore devised to measure n_r in the wind-tunnel; and, with its aid, modifications were tested on a model with the object of reducing the self-excited oscillations in flight. Measurements of n_r were made over a range of Reynolds numbers, and for different periods of oscillation of the model. The final comparison of the flight and wind-tunnel tests, after certain refinements in technique of the former, and after corrections for solid friction to the latter had been made, showed that the full-scale measurement of n_r was about 10 per cent. less than that obtained in the tunnel. It was found possible, without altering the value of n_v to increase the value of n_r to the estimated value. The "snaking" tendencies of the model, which were more pronounced at small angles of incidence, could be greatly reduced by fitting an upper dorsal fin.—(1.8).

Effect of high-lift devices on the static-lateral-stability derivatives of a 45° sweptback wing of aspect ratio 4·0 and taper ratio 0·6 in combination with a body. J. H. Lichtenstein and J. L. Williams. N.A.C.A. Technical Note 2819.

This paper contains the results of wind-tunnel tests to determine the effects of plain and split trailing-edge flaps, with and without leading-edge slats, on the low-speed static-lateral-stability derivatives of a 45° swept-back wing—body configuration. Comparisons between the increments obtained from experiment and those evaluated by simple sweep theory in combination with measured lift and drag increments are also made.—(1.8).

An analysis of the errors in curve-fitting problems with an application to the calculation of stability parameters from flight data. M. Shinbrot. N.A.C.A. Technical Note 2820.

The problem of assessing the errors in the parameters obtained from a curve-fitting process is considered, and a scheme which may be applied toward the solution of such problems is obtained. This method is then specialised to the problem of finding the errors in the calculated stability parameters of an aeroplane, and an example is given.—(1.8).

WINGS AND AEROFOILS

See also BOUNDARY LAYER

No. 2, 11½ ft. wind-tunnel tests of a small span, small chord double aileron for use as a lateral control on a high-lift aircraft. A. D. Young and W. S. D. Marshall. R. & M. 2536.

Tests were made on a 1/2·25 scale model of a half wing of the Master. The span of the aileron was 0·05 chord. Measurements were made of the hinge moments, lift increments (from which the rolling moments were deduced) and the pressure in the aileron gaps just above and below the seals. The latter were required for estimating the effect of internal shrouded nose (or pressure) balances. Tests were also made of the effect on the hinge and rolling moments of a small spoiler situated just aft of the front aileron vent; the spoiler was assumed to emerge on the lower surface of the down-going aileron and on the upper surface of the up-going aileron.—(1.10 × 1.8).

Aerofoil theory of a flat delta wing at supersonic speeds. A. Robinson. R. & M. 2548.

Lift, drag, and pressure distribution of a triangular flat plate moving at a small incidence at supersonic speeds are given for arbitrary Mach number and aspect ratio. The values obtained for lift and drag are compared with the corresponding values obtained by strip theory. The possibility of further application of the analysis leading up to these results is indicated.—(1.10).

Experiments giving hinge moment and lift on a N.A.C.A. 0015 aerofoil fitted with a 40 per cent. control, with especial reference to effect of curvature of control surface. A. S. Batson, J. H. Preston and J. H. Warsap. R. & M. 2698.—(1.10)

Formulas for the supersonic loading, lift and drag of flat swept-back wings with leading edges behind the Mach lines. Doris Cohen. N.A.C.A. Report 1050.

The method of superposition of linearised conical flows has been applied to the calculation of the aerodynamic properties, in supersonic flight, of thin flat, swept-back wings at an angle of attack. The wings are assumed to have rectilinear plan forms, with tips parallel to the stream, and to taper in the conventional sense. The investigation covers the moderately supersonic speed range where the Mach lines from the leading-edge apex lie ahead of the wing. The trailing edge may lie ahead of or behind the Mach lines from its apex. The case in which the Mach cone from one tip intersects the other tip is not treated. Formulas are obtained for the load distribution, the total lift, and the drag due to lift. It has been found possible to give practical formulas which permit the total lift and drag to be calculated to within 2 or 3 per cent of the accurate linearised-theory value. The local lift can be determined accurately over most of the wing, but the trailing-edge-tip region is treated only approximately. Charts of some of the functions derived are included to facilitate computing, and several examples are worked out in outline.—(1.10 × 1.2).

Airfoil profiles for minimum pressure drag at supersonic velocities—general analysis with application to linearised supersonic flow. D. R. Chapman. N.A.C.A. Report 1063.

A derivation is presented of the basic equations which determine the supersonic aerofoil profile having minimum pressure drag for certain prescribed structural requirements. The basic equations are applicable to a variety of practical structural requirements, and can be used with either linear, second order, or shock-expansion aerofoil theory. A solution of the basic equations is found in closed form using linear aerofoil theory. The pressure drag of the optimum profile is compared to that of the biconvex and double-wedge profiles. A graphical method of determining an optimum aerofoil is developed and applied to several examples.—(1.10 × 1.2).

A comparative examination of some measurements of airfoil section lift and drag at supercritical speeds. G. E. Nitzberg and S. M. Crandall. N.A.C.A. Technical Note 2825.

Systematic trends in the lift- and drag-coefficient variation with Mach number for a number of relatively thick aerofoil sections at moderately supercritical speeds are pointed out. Shortcomings of transonic similarity rules are discussed and a semi-empirical correlation of drag data is presented. Differences between the drag curves for various aerofoils are reduced by basing drag coefficient on total pressure rather than dynamic pressure. The initial supercritical loss of lift of aerofoil sections having supersonic flow over the upper surface only is shown to result primarily from pressure changes on the lower surface.—(1.10 × 1.2).

AEROELASTICITY

An experimental investigation on the flutter characteristics of a model flying wing. N. C. Lambourne. R. & M. 2626.

This report describes some preliminary experimental work that has been carried out in an attempt to gain information

on the flexural-torsional flutter characteristics of flying wing types of aircraft. Tests were made with two flexible tip-to-tip models; one of rectangular form, the other of cranked and tapered plan form. The method of supporting the models in the wind tunnel allowed certain bodily freedoms to be present, either singly or simultaneously, and measurements were made of critical speeds and frequencies, and in a few cases the flutter motion was analysed by means of cinematograph records. The experimental results are in no way conclusive and cannot be directly applied to full-scale problems, but they do point to some of the difficulties in the treatment of the flutter of flying wings.—(2.0).

A criterion for the prevention of spring-tab flutter. A. R. Collar and G. D. Sharpe. R. & M. 2637.

This paper advances a formula which can be used as a criterion for the degree of mass-balance necessary for the avoidance of spring-tab flutter. The criterion comprehends within itself the requirement limiting the length of a mass-balance arm. While the formula is based on theoretical considerations the numerical values for the quantities to be used have been deduced from flight experience, which shows excellent correlation with the theory. Two forms for the criterion are given: a simple form suitable for general application, and a slightly elaborated form intended for application to unusually large tabs.—(2.0).

Theoretical investigations of ternary lifting surface—control surface—trimming tab flutter and derivation of a flutter criterion. H. Wittmeyer. R. & M. 2671.

Theoretical investigations have been made of the flutter of an idealised trimming tab system having three degrees of freedom—normal translation of the main lifting surface, rotation of the control surface and rotation of the tab. All the structural parameters of the system have been varied except the out-of-balance moment of the control surface. The cases in which the system is free from flutter have been particularly investigated. The results are applicable to trimming tabs, servo-tabs with zero follow-up ratio, and generally to all systems in which the tab can be regarded as connected elastically only to the control surface.—(2.0).

ELECTRONICS

Trial and evaluation of trailing antenna modification on North Star aircraft. R.C.A.F. C.E.P.E. Report 969.

The trailing antenna system of the North Star aircraft had very poor medium frequency radiation output subsequent to moving the antenna from a forward location to the tail cone. This report describes a modification to the installation to improve the radiation capabilities.—(11.0).

FLIGHT TESTING

Performance Reduction

Measurements of temperature variations in the atmosphere near the tropopause with reference to airspeed calibration by the temperature method. L. J. Lina and H. H. Ricker, Jr. N.A.C.A. Technical Note 2807.

Measurements of temperature variations in the atmosphere near the tropopause over land in the vicinity of Langley Field, Va., are presented. This investigation was made for the purpose of obtaining information on the accuracy of the temperature method (N.A.C.A. T.N. 2046) of air speed calibration over the range of Mach number from 0·6 to 0·8. The temperature surveys and the description of a specially designed thermometer are also presented.—(13.1 × 24).

FUELS AND LUBRICANTS

Literature survey of the effect of sub-zero temperatures on fuels and lubricants. J. M. Lloy. N.R.C. Canada Report No. MP-9.

The report reviews the extensive literature available on the sub-zero temperature operation of aircraft and vehicles with particular emphasis on fuels and lubricants. 322 abstracts of this literature are presented under headings of Batteries, Aeroplanes, Vehicles, Diesels, Dilution, Greases, Pour Points, Refrigeration and Viscosity.—(14.0 × 30.1).

Oils

Bonding of molybdenum disulphide to various materials to form a solid lubricating film. II—Friction and endurance characteristics of films bonded by practical methods. D. Godfrey and E. E. Bisson. N.A.C.A. Technical Note 2802.

The use of molybdenum disulphide MoS_2 as a solid-film lubricant, in applications where designs or higher temperatures preclude liquid lubricants, is extended because of the good frictional and thermal characteristics of MoS_2. An investigation was conducted to determine (1) practical methods of bonding MoS_2 to materials to form solid-film lubricants and (2) friction and endurance characteristics of films so formed.—(14.2).

HYDRODYNAMICS

Planing Surfaces

The planing characteristics of a surface having a basic angle of dead rise of 20° *and horizontal chine flare. W. J. Kapryan and I. Weinstein. N.A.C.A. Technical Note* 2804.

A high-speed investigation was conducted to determine the hydrodynamic characteristics of a planing surface having an angle of dead rise of 20° and horizontal chine flare. The data indicate that the planing characteristics at a given trim depend only on lift coefficient.—(17.2).

Theory and procedure for determining loads and motions in chine-immersed hydrodynamic impacts of prismatic bodies. E. Schnitzer. N.A.C.A. Technical Note 2813.

A theoretical method is derived for computing the motions and hydrodynamic loads during water landings of prismatic bodies involving appreciable immersion of the chines. A simplified method of computation covering flat-plate and V-bottom bodies with beam-loading coefficients greater than unity is given as a separate section. Comparisons of theory with experiment are presented as plots of impact lift coefficient and maximum draft-beam ratio against flight-path angle and as time histories of loads and motions.—(17.2).

The application of planing characteristics to the calculation of the water-landing loads and motions of seaplanes of arbitrary constant cross section. R. F. Smiley. N.A.C.A. Technical Note 2814.

The general equations governing the fixed-trim water landing of a straight-keel seaplane of arbitrary constant cross section are presented in such a form that the landing motions and loads are expressed in terms of the steady-planing characteristics of the seaplane. In order to verify the general validity of these equations, solutions are made for the water landing of a rectangular flat plate and are compared with experimental impact data. Calculated and experimental time histories of draft, velocity, and load are in good agreement. A survey is made of the available information on seaplane planing characteristics which is suitable for use with the analysis of the paper.—(17.2).

A theoretical investigation of the effect of partial wing lift on hydrodynamic landing characteristics of V-bottom seaplanes in step impacts. J. L. Sims and E. Schnitzer. N.A.C.A. Technical Note 2815.

A theoretical investigation is made of the loads and motions in water-landing impacts of wide prismatic V-bottom seaplanes for constant partial wing-lift conditions where the resultant velocity of the seaplane is normal to the keel. An approximate method is given for applying the results of this investigation to the more general case of oblique impact..—(17.2).

Water-pressure distributions during landings of a prismatic model having an angle of dead rise of 22½° *and beam-loading coefficients of* 0·48 *and* 0·97. *R. F. Smiley. N.A.C.A. Technical Note* 2816.

As part of an overall programme, smooth-water landing tests of a primatic float having an angle of dead rise of 22½° were made. Water-pressure, velocity, draft, and acceleration data are presented. Landings were made for beam-loading coefficients of 0·48 and 0·97 at fixed trims between 0·2° and 30·3° for a range of flight-path angles from 4·6° to 25·9° and also for 90°. The experimental pressure distributions

are found to be in fair agreement with the predictions of the available theory; however, better agreement is obtained by modification of the theory.—(17.2).

MATERIALS

Metallic Materials

Effects of cyclic loading on mechanical behavior of 24S-T4 and 75S-T6 aluminum alloys and S.A.E. 4130 steel. C. W. MacGregor and N. Grossman. N.A.C.A. Technical Note 2812.

An investigation was conducted to determine the effects of cyclic loading on the mechanical behaviour of 24S-T4 and 75S-T6 aluminium alloys and SAE 4130 steel. Specimens of the three materials were subjected to various numbers of prior fatigue cycles both below and above the fatigue limits. Special slow-bend tests were employed to show the effects of prior cycles of fatigue stressing on the transition temperature to brittle fracture for SAE 4130 steel and on the energy-absorption capacity of the aluminium alloys. Micrographic studies were made to observe and measure crack formation and propagation and additional special tests were conducted to supplement the results of the slow-bend tests. These included Charpy impact tests, microhardness surveys, tension tests, and fretting-corrosion studies.—(21.2).

Non-Metallic Materials

Effects of moderate biaxial stretch-forming on tensile and crazing properties of acrylic plastic glazing. B. M. Axilrod, M. A. Sherman, V. Cohen and I. Wolock. N.A.C.A. Technical Note 2779.

Effects of approximately 50 per cent bi-axial stretch-forming on the tensile and crazing properties of polymethyl methacrylate were determined. Specimens from formed and unformed pieces of the same sheets were subjected to standard tensile tests, stress-solvent crazing with benzene, long-time tensile loading, and accelerated weathering.—(21.3).

Sandwich Materials

Compression tests on Dural-Celluboard sandwich panels. K. H. V. Britten. R. & M. 2658.

Results are given of compression tests made on 56 Dural-Celluboard Sandwich Panels with Birch Spruce or Whitewood centres. These are compared with results from similar tests on Dural-Balsa sandwich and all-metal panels, and it is seen that over the range of sizes and weights considered Dural-Celluboard can be equally, or more, efficient for carrying end loads.—(21.5.)

MATHEMATICS

Improper integrals in theoretical aerodynamics. K. W. Mangler. A.R.C. Current Paper 94.

Improper integrals occur in theoretical aerodynamics, if one determines the velocities, induced by a vortex sheet, which e.g. may represent the influence of a thin wing at incidence. The velocity at any point can be expressed as an integral involving an influence function, which becomes singular as this point approaches the vortex sheet. As is well known, the principal value, as defined by Cauchy is to be taken in this case. This paper deals with an integral, involving a "principal value of the order n." It was first introduced by Hadamard and is a generalisation of Cauchy's principal value. These integrals can usefully be applied in many theoretical problems, in particular in the supersonic theory of conical fields. In order to deal with the singularities as they occur near the leading edge of a thin wing due to the vorticity tending to infinity there, "principal values of a fractional order" are also introduced. The rules for the evaluation, the differentiation and integration by parts of such an improper integral are derived and summarised together with a theorem, which will be useful to workers in this field.—(21.1).

MECHANICAL ENGINEERING

Bearings

Investigation of wear and friction properties under sliding conditions of some materials suitable for cages of rolling-contact bearings. R. L. Johnson, M. A. Swikert and E. E. Bisson. N.A.C.A. Report 1062.

The wear and the friction of brass, bronze, beryllium copper, monel, Nichrome V, 24S-T aluminium, nodular iron, and grey cast iron sliding against hardened SAE 52100 steel were studied.—(23.1).

Lubrication and cooling studies of cylindrical-roller bearings at high speeds. E. F. Macks and Z. N. Nemeth. N.A.C.A. Report 1064.

Oil inlet distribution (5 methods were investigated) and oil inlet temperature (100° to 205° F.) were found to be significant factors in the cooling effectiveness of a given quantity of oil. Dimensional analysis was used to generalise the test-rig results so that it is possible to predict the inner- or outer-race temperatures above oil inlet temperature from a single curve regardless of whether speed, load, oil flow, oil inlet temperature, oil-jet diameter or any combination of the parameters is varied.—(23.1).

Short-bearing approximation for full journal bearings. F. W. Ocvirk. N.A.C.A. Technical Note 2808.

A short-bearing approximation of pressure distribution in the oil film is presented which is an extension of the pressure-distribution function of Michell and Cardullo and includes end-leakage effects. Equations giving applied load, attitude angle, location and magnitude of peak film pressure, friction, and required oil flow rate as functions of the eccentricity ratio are also given. Curves determined by this analysis are compared with previously published experimental data and theoretical curves of Sommerfield and Cameron and Wood.—(23.1).

Servo-mechanisms

Automatic control systems satisfying certain general criterions on transient behavior. A. S. Boksenbom and R. Hood. N.A.C.A. Report 1068.

An analytical method is presented for the design of automatic controls that starts from certain arbitrary criterions on the behaviour of the controlled system and gives those physically realisable equations that the control system can follow in order to realise this behaviour. Detailed examples for several cases in the control of a turbo-jet engine are presented.—(23.3).

POWER PLANTS

Engines—Gas Turbine

See also Thermodynamics—Heat Transfer

Simulation of linearized dynamics of gas-turbine engines. J. R. Ketchum and R. T. Craig. N.A.C.A. Technical Note 2826.

A general method of simulation is presented, whereby linearised dynamics of gas-turbine engines may be simulated in most orderly fashion with greatest economy of equipment and with most direct use of engineering data. Correlation of experimental and simulated responses of a turbo-jet engine are shown. Use of generalisation factors in determining the coefficients necessary for simulation of engine dynamics is discussed.—(27.1).

Engines—Piston

Torsional vibration in aircraft power plants: methods of calculation. Part I. Introduction and general comments. Part II. Practical treatment of the general problem. Part III. Practical calculations for a typical 12-*cylinder Vee engine. B. C. Carter. R. & M.* 2739.

The object of this report is to assist designers of aircraft power plants to avoid harmful torsional vibration of the crankshaft system. The report is in three parts as follows:

Part I. Introduction and general comments.
Part II. Practical treatment of the general problem.
Part III. Practical calculation for a typical 12-cylinder Vee-engine.—(27.2).

RESEARCH

General—Equipment

*Deflection and diffusion of a light ray passing through a boundary layer. H. W. Liepmann. Douglas Report SM-*14397.

The deflection of a light ray passing through a boundary layer is discussed. The mean deflection is easily obtained and does not depend upon the detailed flow in the layer, but only on the ratio of the initial refractive index to the index in the medium in which the observation takes place.

The fluctuations in the deflection angle due to turbulent density fluctuations are studied on the basis of geometrical optics. For small fluctuations the fundamental equation of geometrical optics may be linearised. The resulting equation for the curvature of the ray is considered for zero initial incidence of the ray and involves two terms: one due to the gradient of the refractive index fluctuations and one due to the mean gradient inter-acting with the fluctuations. The equation can be solved and the root mean square deflection, the diffusion of the ray, can be expressed in terms of the correlation function of the gradient of the refractive index. A crude estimate for a typical case is given.—(31.1).

Investigation of a diffraction-grating interferometer for use in aerodynamic research. J. R. Sterrett and J. R. Erwin. N.A.C.A. Technical Note 2827.

A low-cost interferometer that is easy to adjust and has a large field of view is described. This instrument, which is based on a principle discovered by Kraushaar, uses small diffraction gratings to produce and recombine separate beams of light. The usual two-parabolic-mirror schlieren system can be converted inexpensively into a diffraction-grating interferometer. Experimental data are presented to verify the ability of the instrument to provide valid and reliable measurements of air density. Photographs of the flow in a supersonic cascade tunnel are included to indicate the quality of the interferograms obtained.—(31.1).

AERODYNAMIC

Design and calibration tests of a 5·5 in. square supersonic wind tunnel. J. Lukasiewicz. R. & M. 2745.

The main design features of the wind tunnel are described and results are given of the investigations made to determine:

(*i*) the minimum pressure ratio required to operate the wind tunnel at Mach numbers up to 3·5, and

(*ii*) the uniformity of the velocity distribution in the working section at Mach numbers of 1·57, 1·88, 2·48, 2·85, 3·25 and 3·5.

It was found that the tunnel pressure recovery can be appreciably increased by means of a contraction ("second throat") located between the working section and subsonic diffuser. All nozzles tested were designed with short throats and expansion profiles with the maximum angles of expansion for the given exit Mach number. Condensation in the wind tunnel nozzle (run with atmospheric air) has a detrimental effect on the velocity distribution in the working section, particularly at small Mach numbers.—(31.2).

STRUCTURES

LOADS

Landing-gear impact. W. Flugge. N.A.C.A. Technical Note 2743.

The report deals with the impact forces in landing gears. Both the landing impact and the taxi-ing impact have been considered, but drag forces have so far been excluded. The differential equations are developed and their numerical integration is shown, considering the non-linear properties of the oleo shock strut. A method is given for determining the dimensions of the metering pin from a given load-time diagram. A review of German literature on landing-gear impact is also presented.—(33.1).

THEORY AND ANALYSIS

*Buckling of a simply supported triangular plate in combined compression and shear. W. H. Wittrick. A.R.L. Australia Report SM.*197.

The problem considered is that of the buckling of a right-angled isosceles triangle, simply supported on all edges and subjected to any uniform system of stress. A determinantal equation is derived from which the critical value of an applied stress system may be obtained. A particularly simple solution is given for the case of uniform compressive stress in all directions. The case of pure shear stress acting parallel to the two perpendicular sides of the triangle is also solved numerically. The case of buckling under the combined systems of compression and shear mentioned above is considered, and an inter-action curve is derived.—(33.2).

*The compressive buckling of a parallelogram plate simply supported along all four edges. J. Guest. A.R.L. Australia Report SM.*199.

Following some recent work on buckling of clamped parallelogram plates, a similar investigation has been made for the case of a simply supported boundary. The problem of a thin rhombus plate with the included angle between the u and v axes being equal to 60° has been considered in detail. The Lagrangian multiplier method has been used to calculate the upper limit to the critical compressive stress.—(33.2).

Torsion tests of aluminum-alloy stiffened circular cylinders. J. W. Clark and R. L. Moore. N.A.C.A. Technical Note 2821.

Results are presented for the second series of torsion tests on aluminium-alloy stiffened circular cylinders, the first series having been reported in N.A.C.A. A.R.R. 4E31. The cylinders were similar in construction except that the wall thickness was 0·020 in. for the first series and 0·32 in. for the second series. The significant observations from both series of tests are summarised and some comparisons are made with more recent theoretical work.—(33.2).

STRUCTURAL TESTING

The physical characteristics of wire resistance strain gauges. E. Jones and K. R. Maslen. R. & M. 2661.

This report deals with the fundamental principles of the wire resistance strain gauge. Types of strain gauge in common use and their methods of construction are described, and the mechanism whereby strain effects change of resistance is discussed. A sub-section is devoted to the behaviour of fine wires, in general, under strain. Possible causes of error, including the effects of humidity and temperature, are discussed, and as far as possible methods are given of overcoming these difficulties. The effect of the passage of current on the strain gauge is described, and methods of increasing output suggested. The final section is devoted to miscellaneous properties of the wire resistance strain gauge, on several of which little information is available at present.—(33.3).

THERMODYNAMICS

Investigation of the effect of the length/diameter ratio of a small-scale combustion chamber on weak flame stability limits. F. G. Kitson. N.A.E., Canada, Laboratory Report L.R. 34.

The scale effect on weak stability limits was studied using propane as fuel in a small-scale combustion apparatus. The stability of the chambers was tested by determining air/fuel ratio limits at which extinction occurs as a function of total air flow (at constant pressure).—(34.1).

HEAT TRANSFER

Analysis of temperature distribution in liquid-cooled turbine blades. J. N. B. Livingood and W. B. Brown. N.A.C.A. Report 1066.

Analytical methods are presented for computing temperature distributions in liquid-cooled turbine blades or in simplified shapes used to approximate sections of liquid-cooled turbine blades. Non-dimensional charts are presented for use in the simplification of some of the calculations. Illustrative examples are also included to demonstrate the use of the various equations and non-dimensional charts and to show trends of the various temperature distributions.—(34.3).

Regenerator heat exchangers for gas-turbines. J. E. Johnson. R. & M. 2630.

A series of tables and curves has been prepared from which the efficiency of a regenerator can be calculated if the operating conditions and heat transfer coefficients are known. The tables and curves cover a range of lengths and blow times appropriate to gas turbine conditions. Measurements of heat transfer and pressure drop coefficients have been made on several examples of matrix of both the gauze and flame trap type in conditions similar to those in a gas turbine. A number of examples have been worked out from the experimental results to show the relative importance of the different variables on the performance of typical regenerators.—(34.3 × 27.1).

APPOINTMENTS

This section of THE JOURNAL *is available for advertisements of appointments in the Industry, the Ministries, Research Establishments, Universities and Colleges in the United Kingdom only.*

Press Day—20th of the month preceding publication.
Rates—8/- a line. Each paragraph is charged separately and name and address must be counted. Semi-displayed setting £2 10s. 0d. per column inch.
Box Numbers—1/- extra. Replies should be addressed to: Box 000, care of THE JOURNAL, Royal Aeronautical Society, 4 Hamilton Place, London, W.1.
Remittances—Cheques and postal orders should be made payable to the Royal Aeronautical Society.
The Society reserves the right to decline any copy or advertisement at its discretion and accepts no responsibility for delay in publication or for clerical or printer's errors, although every care is taken to avoid mistakes.

THE ENGLISH ELECTRIC CO. LTD., LUTON, have a vacancy for a Senior Aerodynamics Engineer for Guided Missile work involving both technical and administrative responsibility. Candidates must have a good degree or equivalent and be interested in pre-project, performance and assessment aspects. Previous experience of supersonics, stability and performance an advantage. Salary according to experience and qualifications. Please write giving full details mentioning reference 1078 to The English Electric Company Ltd., 336/337 Strand, London, W.C.2.

SENIOR TECHNICIAN required for interesting work on general flutter and vibration problems for new projects. Some experience, particularly in aircraft structures, is essential, and a good engineering or mathematics degree, or equivalent qualification, is necessary.

Details of housing accommodation available and facilities for removal, supplied at interview.

Applications in writing, stating age, qualifications, experience and salary required to the Personnel Manager, Short Brothers & Harland Limited, Queen's Island, Belfast.

DESIGN DRAUGHTSMEN

Vacancies exist for Senior and Junior Design Draughtsmen in the Engineering and Research Departments of the Company.

Applicants with previous experience in the design of aircraft instruments, electrical/electronic equipment and small mechanisms will be preferred, but general technical ability will be the first consideration. Permanent progressive posts, with superannuation benefits.

Apply to Personnel Manager, Smiths Aircraft Instruments Ltd., Bishops Cleeve, near Cheltenham, quoting references, full particulars of previous experience, and salary required.

ELECTRICAL DRAUGHTSMEN required for design of special aircraft electrical equipment.

Apply Employment Manager, Vickers-Armstrongs Limited (Aircraft Section), Weybridge, Surrey.

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD., ARMAMENTS DIVISION, have vacancies for Senior and Intermediate Designers, Stressmen and Aerodynamicists to undertake design and development work on Guided Missiles. Applicants should have sound qualifications and aeronautical experience but not necessarily in the Guided Missile field. Applications to the Chief Engineer, Sir W. G. Armstrong Whitworth Aircraft Ltd., Armaments Division, Baginton, nr. Coventry.

GUIDED WEAPONS DEVELOPMENT offers good opportunities for Senior and Junior Electrical, Electronic, Radio and Mechanical Engineers and Draughtsmen, Aerodynamicists, Technical Authors, and Computors (female).

Apply quoting reference G.W. and giving particulars, qualifications and experience, to the Employment Manager, Vickers-Armstrongs Limited (Aircraft Section), Weybridge, Surrey.

AERODYNAMICIST required by The English Electric Co. Ltd., Luton, for work on supersonics with particular application to the study of oscillating aerofoil theory. Candidates must have a good degree, aptitude for mathematics and experience in theoretical aerodynamics. Post Graduate qualifications an advantage. Salary according to experience and qualifications. Write giving full details, mentioning reference 457D, to The English Electric Company Ltd., 336/337 Strand, London, W.C.2.

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD., ARMAMENTS DIVISION, have vacancies for Senior and Intermediate Draughtsmen and Stressmen to undertake design and development work on Guided Missiles. Applicants should have sound qualifications and preferably some aeronautical experience. Good salaries and prospects for the right type of men. Applications to the Chief Engineer, Sir W. G. Armstrong Whitworth Aircraft Ltd., Armaments Division, Baginton, nr. Coventry.

(Continued)

DOWTY EQUIPMENT LIMITED

require

FIRST-CLASS SOUND PRACTICAL ENGINEERS

preferably with some experience of design, development and testing of jet engine accessories, particularly flow, acceleration and speed governing controls, burners and pumps. Exceptional prospects of advancement.

SENIOR DRAUGHTSMEN

for development work on Fuel Systems. Experience on light hydraulic or pneumatic controls acceptable.

SENIOR DRAUGHTSMEN

for Hydraulic and Undercarriage Department.

Also

JIG AND TOOL DRAUGHTSMEN
STRESSMAN
and
TECHNICAL WRITER

Important positions with prospects.

The Company's conditions are exceptionally good; there is a realistic pension scheme and the environment is ideal. The Company employs a Housing Officer who will render every assistance.

Write, preferably in tabulated form, to:

PERSONNEL MANAGER
DOWTY EQUIPMENT LIMITED
CHELTENHAM

VICKERS-ARMSTRONGS LIMITED
(AIRCRAFT SECTION)
WEYBRIDGE

Have vacancies for:

AIRCRAFT DESIGN DRAUGHTSMEN
(Senior, Intermediate and Junior)
RADIO and ELECTRICAL DRAUGHTSMEN
STRUCTURAL DRAUGHTSMEN
STRESSMEN
AERODYNAMICISTS
SENIOR WIND TUNNEL TECHNICIANS
WEIGHTS ENGINEERS
JIG AND TOOL DRAUGHTSMEN
MECHANICAL TEST ASSISTANTS
(Electrical and Metallurgical)

Apply:

EMPLOYMENT MANAGER
VICKERS-ARMSTRONGS LIMITED
(Aircraft Section)
WEYBRIDGE SURREY

APPOINTMENTS

This section of THE JOURNAL *is available for advertisements of appointments in the Industry, the Ministries, Research Establishments, Universities and Colleges in the United Kingdom only.*

Press Day—20th of the month preceding publication.
Rates—8/- a line. Each paragraph is charged separately and name and address must be counted. Semi-displayed setting £2 10s. 0d. per column inch.
Box Numbers—1/- extra. Replies should be addressed to: Box 000, care of THE JOURNAL, Royal Aeronautical Society, 4 Hamilton Place, London, W.1.

Remittances—Cheques and postal orders should be made payable to the Royal Aeronautical Society.
The Society reserves the right to decline any copy or advertisement at its discretion and accepts no responsibility for delay in publication or for clerical or printer's errors, although every care is taken to avoid mistakes.

A **VACANCY** exists for a **Chief Stressman** to take charge of department dealing with pneumatic and hydraulic components, wheels and brakes. Degree essential. Preferably with knowledge of M.O.S. and A.R.B. Design approval procedure. Please write giving details of qualifications and experience to General Manager, Dunlop Rubber Co. Ltd., Aviation Division, Foleshill, Coventry.

S. SMITH & SONS (ENGLAND) LIMITED, Bishops Cleeve, Cheltenham, the parent Company of Smiths Aircraft Instruments Ltd., have a number of immediate and future vacancies in their Laboratories for Research Engineers, Physicists and Development Engineers for work on Guided Weapons, Aircraft Instruments and Automatic Pilots. The vacancies are at various levels of responsibility. For the more senior posts applicants should have an Honours Degree or equivalent and must be capable of leading a team and have knowledge and experience in one or more of the following fields:—

(a) Servo Mechanisms.
(b) Aerodynamics.
(c) Electronics (preferably including Magnetic Amplifiers).
(d) Instrument Mechanisms.
(e) Small Electric Motors.

Other posts are available for applicants with qualifications ranging from Higher National Certificate to Honours Degree, preferably with knowledge and experience in one or more of the above fields.

The scale of commencing remuneration will range, according to age, record and technical qualifications, from £550 to £1,500 per annum. All posts are pensionable and accommodation assistance will be afforded successful applicants, with guaranteed housing after completion of a satisfactory probationary period. Applications are to be made on the appropriate forms (quoting Ref. GW1/J), obtainable from the Personnel Manager at the above address.

HANDLEY PAGE (Reading) LIMITED, The Aerodrome, Woodley, Reading, have vacancies in their Design Offices, on an interesting civil project for Section Leader and Senior Structural Stress Engineers and also for a Weights Engineer. High salaries offered and good opportunities for advancement in an expanding Design Office. Every effort will be made to assist with housing accommodation. Write giving full particulars to the Personnel Officer.

MINISTRY OF SUPPLY invites applications for a limited number of **SENIOR** and **JUNIOR FELLOWSHIPS** tenable for two or three years at the Royal Aircraft Establishment, Farnborough.

Fellows will be required to carry out fundamental research in aerodynamics or aeronautical structures, the subjects being selected according to the training and experience of the Fellows and the needs of the Establishment.

Candidates must be British subjects and Honours graduates in Natural Science, Engineering or Mathematics. Candidates for Junior Fellowships should normally have had at least two years' post-graduate research experience and should preferably be aged 23-26; for Senior Fellowships they should have had at least three years' post-graduate research experience and should preferably be aged 26-30.

Remuneration will depend on individual merit and will be between £800-£1,000 per annum for Senior Fellows and £500-£700 per annum for Junior Fellows. Fellowships carry F.S.S.U. benefits. At the expiry of a Fellowship the holder may be considered for a permanent post at the Establishment if he so desires.

Application forms are obtainable from the Director, Royal Aircraft Establishment, Farnborough, Hants., to whom completed forms, together with suitable testimonials regarding research ability and, where possible, copies of candidates' published papers, must be returned by **1st MARCH 1953.** Overseas candidates should submit written applications stating age, nationality and place of birth of self and parents, educational and academic qualifications, appointments held and research experience.

CHANGES OF ADDRESS

Changes of address should be notified promptly to ensure delivery of the Journal.
When notifying changes please give the following particulars:—

1. Name (in block letters).
2. Grade of membership.
3. New address (in block letters).
4. Old address.

This information should be sent to:

The Secretary
THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, LONDON, W.1

Royal
at its
or for
istakes.

lrome,
Offices.
Senior
gineer.
ement
ade to
articu-

imited
enable
nment,

search
being
of the

duates
didates
ast two
ferably
had at
should

will be
£500-
carry
holder
shment

Royal
n com-
garding
didates'
1953.
stating
educa-
ld and

SOCIETY